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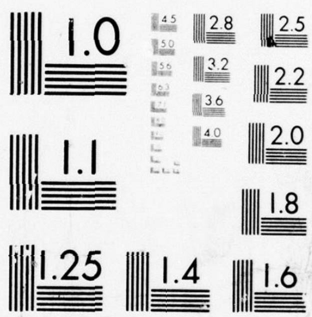

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HUBERTUS STRUGHOLD, M.D., Ph.D.

USAF SCHOOL OF AEROSPACE MEDICINE
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A second volume of a compendium of previously unpublished papers of Dr. Hubertus Strughold has been compiled to commemorate the dedication of the Hubertus Strughold Aeromedical Library at the USAF School of Aerospace Medicine. Dr. Strughold is acknowledged as a pioneer in aviation medicine and is known as the "Father of Space Medicine." This compendium covers a wide range of topics related to aerospace medicine.

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PREFACE

On 19 January 1977 the Aeromedical Library in the USAF School of Aerospace Medicine, Aerospace Medical Division, Air Force Systems Command, Brooks Air Force Base, Texas, was renamed the "Hubertus Strughold Aeromedical Library" in special ceremonies honoring the retired chief scientist of the Aerospace Medical Division. Dr. Strughold is a pioneer in aviation medicine and has earned the right to be called the "Father of Space Medicine."

The library, built in 1963, houses medical, technical, and scientific works that are required for the research and teaching programs at the USAF School of Aerospace Medicine. With over 118,000 volumes and 2,000 current journals, the facility is the largest medical library in the Air Force.

To commemorate the rededication of the library, this second volume of a compendium of previously unpublished papers of Dr. Hubertus Strughold has been compiled. The collection will serve as a valuable resource to students of aviation medicine.

L. J. Enders
LAWRENCE J. ENDERS
Colonel, USAF, MC
Commander
USAF School of Aerospace Medicine

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I would like to express my appreciation to Marion Green, Sue Bensinger, and Angelina Davis, of the Medical Editing Section, USAF School of Aerospace Medicine, for their excellent editorial assistance.

Hubertus Strughold

HUBERTUS STRUGHOLD, M.D., Ph.D.

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HUBERTUS STRUGHOLD, M.D., Ph.D.

HUBERTUS STRUGHOLD, M.D., Ph.D.

BIOGRAPHY

Hubertus Strughold was born in Westfalia, Germany, on 15 June 1898. He studied medicine and natural sciences at the Universities of Muenster, Goettingen, Munich, and Wuerzburg and received his Ph.D. degree from the University of Muenster in 1922. He received his M.D. degree from the University of Wuerzburg the following year.

After receiving his degrees, Dr. Strughold served as research assistant to Professor Max von Frey at the Physiological Institute in Wuerzburg until 1928. Specializing earlier in aviation medicine, Dr. Strughold gave the first lecture ever on that subject in 1927 at the University of Wuerzburg. When he told his students that thousands of people would be flying across the Atlantic in ten years, they laughed. But they stopped laughing ten days later when Charles Lindbergh made his historic flight across the Atlantic.

As a Fellow of the Rockefeller Foundation from 1928 to 1929, Dr. Strughold performed research at Western Reserve University in Cleveland, Ohio, under Professor Carl Wiggers, and at the University of Chicago under Professor A. Carlson.

From 1929 to 1935, Dr. Strughold was research assistant and associate professor in Physiology and Aviation Medicine at Wuerzburg. He was director of the Aeromedical Research Institute in Berlin and associate professor of Physiology at the University of Berlin from 1935 to 1945.

After World War II, Dr. Strughold became professor of Physiology and director of the Physiological Institute at the University of Heidelberg. In 1947, he accepted an invitation to join the staff of the USAF School of Aviation Medicine at Randolph Field, Texas, and has been active in the Air Force aerospace medical program ever since.

Major General Harry Armstrong, then a colonel and commandant of the School of Aviation Medicine, created the Department of Space Medicine, with Dr. Strughold in charge, in 1949. This department was the result of General Armstrong's realization that jet and rocket aircraft were taking men into a region so far above the ground that it was physiologically indistinguishable from space.

During the next eight years, the Department of Space Medicine started the medical groundwork for the man-in-space program which was adopted as a national policy of the United States. The first studies of the environmental effects of space travel were conducted at the Department. At Dr. Strughold's suggestion, the Department also designed and built to his specifications the first space cabin simulator, which was in effect a laboratory prototype of a spacecraft similar to those used for the space program.

In 1951, the Air University, which included under its command all the educational functions, conferred the academic title Professor of Aviation Medicine on Dr. Strughold. It named him Professor of Space Medicine in 1958. He is still the only person to be so honored, and for this reason he is often referred to as the "Father of Space Medicine."

Dr. Strughold became a naturalized citizen of the United States on 20 July 1956.

From 1957 to 1962, Dr. Strughold held the position of Adviser for Research at the School of Aviation Medicine, USAF, Randolph AFB, and at the newly formed Aerospace Medical Center, Brooks AFB, Tex. In 1960, he was assigned the additional duty of chairman of the Advanced Studies Group at the Center.

When the Air Force Systems Command organized the Aerospace Medical Division (AMD) in 1962 to supervise the conduct of aerospace medicine research for the Air Force and in support of the national space program, Dr. Strughold became chief scientist of the new organization. Throughout his career with the Air Force, Dr. Strughold exerted a great deal of influence on research of the medicobiological problems encountered in the "vertical frontier."

Dr. Strughold held the position of chief scientist at AMD until his retirement in 1968. At that time, he was named honorary consultant to AMD.

Dr. Strughold is the author and coauthor of several books. Perhaps the best-known of these is *Your Body Clock (Its Significance for the Jet Traveler)*, which deals with the effects of travel across time zones and in space on the body clock. He also wrote *The Green and Red Planet: A Physiological Study of the Possibility of Life on Mars*, and he co-authored the textbook, *Principles and Practices of Aviation Medicine.* He was coeditor of the book, *Physics and Medicine of the Atmosphere and Space*, and has authored over 180 professional papers on physiology, aviation medicine, and space medicine.

Dr. Strughold is responsible for many of the terms used daily in the field of aerospace medicine. These terms include "bioastronautics," which concerns itself with the effects of space travel on man; "gravisphere," the area within which the gravitational field of a body is dominant; and "astrobiology," the study of the forms and phenomena of life on celestial bodies.

Notable scientific contributions by Dr. Strughold include the following:

a. Effects of global flight on the day-night cycle of the human body.

b. Levels of the Earth's atmosphere where conditions are comparable to those in space (known as "atmospheric space equivalence," another term coined by Dr. Strughold).

c. Regions favorable to life in the solar system ("ecosphere," another of his terms).

d. Studies of Earth organisms under simulated Martian conditions.

e. Development of a geography of space ("spatiography," yet another term coined by Dr. Strughold).

f. Visual problems in space flight.

Dr. Strughold has been the recipient of numerous professional awards and honors. For his pioneer research in space medicine, he received the Herman Oberth Medal of the German Rocket Society in 1954; the Theodore C. Lyster Award of the Aerospace Medical Association in 1958; the Exceptional Civilian Service Award, presented by Secretary of the Air Force James H. Douglas, Jr., in 1958; and the John J. Jeffries Award of the Institute of Aeronautical Sciences in 1959.

He was also awarded the Melbourne W. Boynton Award of the American Astronautical Society, Inc., in 1964, and several other awards from Yugoslavia, Sweden, and Hungary, as well as the United States.

In 1970 the editor of the *Mark Twain Journal* conferred the title "A Grand Knight of Mark Twain" on Dr. Strughold in recognition of his outstanding contributions to modern medical science.

One of the greatest honors bestowed on Dr. Strughold was his induction into the International Space Hall of Fame, Alamogordo, New Mexico, on 6 October 1978.

SPEECH PRESENTED AT INDUCTION INTO THE
INTERNATIONAL SPACE HALL OF FAME, ALAMOGORDO, NEW MEXICO

6 October 1978

Hubertus Strughold, M.D., Ph.D.

Today's induction into the International Space Hall of Fame, in Alamogordo, New Mexico, is the highest honor in my life and I am deeply grateful.

I wish to express my sincere appreciation to each member of the selection committee and the Commission for bestowing this honor upon me. Likewise, I want to thank all of my colleagues, coworkers and associates in the space program for their inspiration and support. Without them I could not have succeeded. Also I want to thank my friends and all of you here for coming to this ceremony.

It might be appropriate at this moment to make a few historic remarks about the interest in space and my connection with space research, or more specifically, space medicine.

When I was a boy, 12 years old, I was lucky to observe the famous Halley's comet for two weeks every evening in 1910. This made me space-minded which was later reflected in my space-oriented medical research and publications.

In 1947 when I first came to the United States, thanks to an invitation from Major General Harry Armstrong, not too many people talked about space. However, in the 1950's the attitude in the United States toward space exploration became very good because of the influence of two famous celebrities.

The late former President Lyndon B. Johnson, then senator, was one of the first politicians to be seriously interested in space. He followed our space medical research at Randolph Air Force Base and Brooks Air Force Base and paid us many visits. Through his efforts in the Congress, and in the White House, the U.S. Government became increasingly space-minded, which led to the founding of NASA. It is my opinion that his early space interest was a political force behind America's fantastic steps into space and the successful landing on the Moon for the benefit of mankind.

The other person was Walt Disney, whom I briefed during an ocean-liner trip to Europe in 1957 about the space medical research at the

School of Aviation Medicine at Randolph AFB, Texas. He made the American people in general space-minded through his many television shows and movies which dealt with space.

When NASA came into being, space medicine played an important role with Dr. William K. Douglas as the first physician of the Mercury Project. Later, I was invited by NASA as an observer in the Control Center at the Johnson Space Center in Houston during all of the Apollo flights and the Skylab flights.

On the theoretical side, I would like to say, I am a member of LIL (Lunar International Laboratory) and MIL (Mars International Laboratory). Both are committees of the International Academy of Astronautics, which are looking into space-, Moon-, and Mars-related application of the future. So much for my personal connection with the space program.

Now this International Space Hall of Fame in Alamogordo will be my galactic home on Earth. Again, thank you very much.

LYNDON B. JOHNSON, THE PROMOTER OF SPACE EXPLORATION

Personal Memoirs by Hubertus Strughold, M.D., Ph.D.

The stories about Lyndon B. Johnson in publications deal essentially with his senatorial and presidential activities concerning diplomacy, politics, the Great Society, education, and his life on his ranch in Texas. His interest in space is revealed especially in the following books.

Space, Its Impact on Man and Society (1965), edited by Lillian Lievy. The title of the contribution of Lyndon B. Johnson in this book is "Politics of the Space Age" in which he made it clear that this new field of science should be only for the benefit of mankind.

In his book, _Earthman, Spaceman, Universal Man_ (1965), Colonel Paul A. Campbell, former commander of the School of Aerospace Medicine, writes: "Special recognition must go to Lyndon Baines Johnson, thirty-sixth President of the United States. Early in his career as Senate leader and far in advance of most of his fellow men, he recognized the vast potentialities inherent in the exploration of space....Without his foresight and backing the space programs of this country might readily be withering away in political doldrums."

The book, _The Quotable LYNDON B. JOHNSON_ (1968), edited by Sara H. Hayes, contains 6 quotations about space exploration. To mention only one brief part of one: "When we ask what this nation or any nation expects to find from exploration of space, the answer is one word: knowledge, we shall need to maintain Earth as a habitable environment for man." (Message to the Senate regarding ratification of the Outer Space Treaty, February 7, 1967.)

In his own biography, _The Vantage Point_ (1971), he devoted one whole chapter to "Space." He mentions in it his activities to establish a civilian space agency (NASA) and his advice to President Kennedy to announce the plan to land a man on the Moon.

Joe B. Frantz in his book, _37 Years of Public Service, The Honorable Lyndon B. Johnson_ (1974), stated that Johnson is recognized as one of the fathers of the United States space program.

In the book, _Lyndon B. Johnson, An American Dream_ (1976), by Doris Kearon are mentioned some of Johnson's space-related activities as Senate leader.

In this article I shall concentrate upon his strong support of the space program, particularly in its early stage when he was Chairman of the Senate Space Committee; and I shall confine myself essentially to my personal contact with his spaceflight support.

It all started in February 1958 when the Department of Space Medicine (founded in 1949 by General Harry Armstrong, Commander of the School of Aviation Medicine at Randolph Field, Texas) conducted an 8-day experiment in a spacecabin simulator, with Airman Farrell as the subject. This made the headlines in the news media. On the evening before the last day of the experiment, we were informed that the Senate Majority Leader, Lyndon B. Johnson, wished to be present at the opening of the spacecabin simulator. When the chamber was opened at 8 o'clock the next morning, February 16, 1958, Lyndon B. Johnson shook hands with the airman and congratulated him in the name of the Nation. General Otis O. Benson, Commander of the School of Aviation Medicine, did the same in the name of the School, and I congratulated him in the name of space medicine (Fig. 1).

Shortly thereafter there was a press conference, with Lyndon B. Johnson present. All this attracted international attention. For instance, the Shah of Iran and his wife, Soraya, visited Randolph Field to see the spacecabin simulator. Then General Benson, Airman Farrell, and I were invited by the Majority Leader of the Senate to a luncheon on February 23, 1958, with Lady Bird Johnson as hostess, in the Caucus Room of the Senate. Present were more than 100 VIPs, including Secretary of Defense McElroy. During the luncheon the Senate Majority Leader asked me to give a brief talk about the problems of space medicine and the significance of this experiment. I did not need to tell a joke, as it is usually done at the beginning of speeches, because I created some amusement when I addressed him as "Minority Leader." All smiled, including him. (By the way, the steak which was served had the shape of Texas, and usually when I tell the story, I say it was so large that I could eat only the Panhandle.) The luncheon was followed by a 30-minute discussion, and it is my feeling that this invitation made the field of space medicine, developed "deep in the heart of Texas," suddenly acceptable to the highest governmental levels on Capitol Hill.

On the 27th of February 1958, Lyndon B. Johnson sent me the following letter (see page 16).

In 1959 Lyndon B. Johnson gave a speech at the Dedication of the Aerospace Medical Center at Brooks Air Force Base in which he praised its research devoted to the safety of flight. Thereafter he made several tours through the various departments to get informed about the up-to-date space medicine research. He also participated as honored guest at several international space symposia, arranged by the School of Aerospace Medicine at Brooks Air Force Base and the Southwest Research Institute at San Antonio.

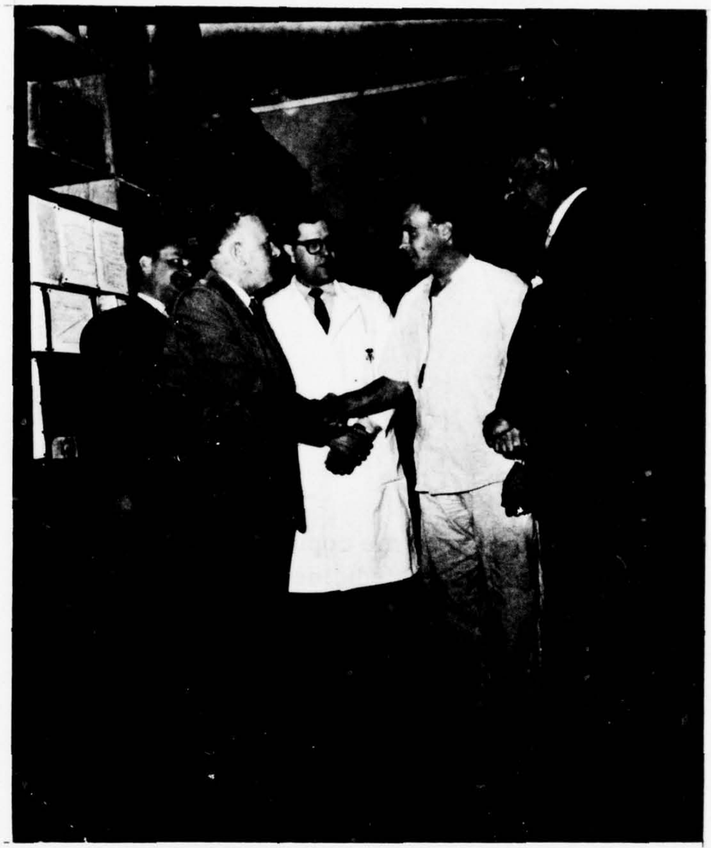

Figure 1. Dr. Strughold greeting Airman Donald G. Farrell as he emerged from a space chamber after an 8-day simulated space voyage at the School of Aerospace Medicine, 16 February 1958. (Left to right) Colonel George R. Steinkamp, Dr. Hubertus Strughold, Captain Julian E. Ward, Airman Donald G. Farrell, and Senate Majority Leader (later President) Lyndon B. Johnson.

LYNDON B. JOHNSON
TEXAS

United States Senate
Office of the Democratic Leader
Washington, D. C.

February 27, 1958

Dear Dr. Strughold:

You are very kind to send me copies of your articles on the development of Space Medicine.

I must say that I have rarely encountered a field of scientific endeavor more interesting than this one, in which you have played so outstanding a part. Nor is there any field of greater immediate concern to this country, and to the world, as we enter the Age of Space.

Let me say, too, that I thoroughly enjoyed being with you on Wednesday, and with your colleagues in that splendid adventure.

With kind regards, I am

Sincerely,

Lyndon B. Johnson

Dr. Hubertus Strughold
School of Aviation Medicine USAF
Randolph Air Force Base, Texas

LYNDON B. JOHNSON, <u>THE</u> PROMOTER OF SPACE EXPLORATION

On the morning of the 16th of July 1969, Lyndon B. Johnson was at Cape Kennedy and witnessed the launching of the Apollo 11, carrying the astronauts to the Moon. He characterized this visual experience as a "majestic and unforgettable panorama."

Four weeks later, I sent him the following letter:

HUBERTUS STRUGHOLD, M. D., PH. D.
PROFESSOR OF SPACE MEDICINE Retired
AEROSPACE MEDICAL CENTER
BROOKS A. F. B., SAN ANTONIO, TEXAS

22 August 1969

My dear Mr. President

At the conclusion of the very successful Apollo 11 flight, I like to take the liberty to express to you my congratulations. Without the support by you during your pre-White House time and White House time, this fantastic achievement in human history would not have been made. I remember your presence at the end of the first 8-day long Airman Farrell experiment in the space cabin simulator at Randolph Field which gave us a tremendous morale boost at the time when space flight and space medicine was generally considered an illusion.

I had the privilege to be present in the Mission Control Center at Houston during the Moon flight and to observe the recorded heart beat and respiration of the astronauts every day. This was the climax in my professional life.

Again, best congratulations and many thanks for your early support of our space medical studies.

Hubertus Strughold

HUBERTUS STRUGHOLD, M.D., Ph. D.

Six days later, I received the following letter:

LBJ

AUSTIN, TEXAS

Dear Dr. Strughold:

Praise from you about my part in the moon landing is high praise indeed. And I just want you to know how grateful I am for your generous and thoughtful letter.

Sincerely,

Dr. Hubertus Strughold, M.D., Ph.D.
Professor of Space Medicine (Retired)
Menger Hotel
San Antonio, Texas

August 28, 1969

This concludes the collection of my space-related LBJ stories. They clearly reflect Lyndon B. Johnson as the actual driving force behind the scene of the United States space program.

MEETING WALT DISNEY IN THE EARLY SPACE AGE

Hubertus Strughold, M.D., Ph.D.

In September 1957 I had the great honor to meet the Hollywood genius Walt Disney during a trip to Europe on the oceanliner Queen Mary. He was on his way to visit a museum in London. I was going to attend the Congress of the International Astronautical Federation meeting in Barcelona, Spain. The first evening there was a reception in his honor. When I introduced myself to him as Chief of the Department of Space Medicine at the School of Aviation Medicine, Randolph Field, Texas, he expressed great interest in man's advance on the vertical frontier, as predicted in science fiction and science vision, and asked me to tell him about the research in Space Medicine.

Every evening after dinner, during a brief walk around the deck of the ship, we had a "space talk." At the last evening he said, "I am now 54 years old; I hope I can still work for 10 more years." I replied, "I hope 20 years." He smiled and went on, "I have seen during my lifetime so many inventions and discoveries that if somebody tells me that, during my still coming lifetime, somebody flies to the Moon -- darned, I believe it." Fourteen days later the first Sputnik was in space; the Space Age had begun! Walt Disney lived about 10 more years, dying in 1966. He had not seen the flight to the Moon, but he saw the preparation of the NASA Apollo Moon Project.

Before we said goodbye on the ship in Le Havre, France, I asked him about the meaning of his name. He told me that his ancestors had lived at the Bay D'Isney on the North Sea in Flanders. From this location they got their name. After the D'Isneys had immigrated to Chicago, they were always asked, "How do you spell your name?" To make it easier, his father changed his name by contracting D'Isney to Disney. Such is the origin, or semantics, of the famous name Disney.

SPACE MEDICINE - THE YOUNGEST OFFSPRING OF AESCULAPIUS*

Hubertus Strughold, M.D., Ph.D.

General medicine, with particular accent on internal medicine, can be regarded as having been the foundation of medicine, and in its modern form has so remained up to the present day. In the course of medical history, many new and important branches have been developed, some based on different methods of treatment (such as surgery) and others specialized with regard to the various anatomical and physiological systems (for instance, neurology, dermatology, gynecology, etc.); still others related to a specific occupation and environment (such as industrial medicine, global medicine, and naval medicine). Thus today, Aesculapius--son of Apollo and Coronis--the Greek and Roman god of medicine, can look with satisfaction upon a rather large family of children, all dedicated to the health, progress, and happiness of mankind. And now, Aesculapius extends his realm into the sky. Some 30 years ago when aviation made its triumphant conquest of the troposphere high up into the stratosphere, across continents and oceans, medicine was always its helping companion. In fact, the specialty "aviation medicine" has contributed greatly toward making flying possible and safe. During the first half of this century, flight was to the lower regions of the atmosphere, the troposphere, and the stratosphere, because the conventional propeller planes and jet planes require an atmosphere of a certain density as a supporting medium. Not so the rocket! This new engine for propulsion, based on Newton's third law of motion--"actioni contrariam semper etaequalem esse reactionem...," or, for every action there is equal but opposite reaction--does not need air as a supporting medium; in fact, it is even more efficient in the absence of air, in a vacuum. And it carries its own oxygen for the combustion of the fuel. The rocket, therefore, has no limitation in altitude whatever. Its operational range is determined exclusively by the fuel. In the realm of rocket flight the concept of height above Earth's surface gradually fades into that of distance from Earth. The rocket alone has really conquered the third dimension in flight. It has opened a new frontier--the vertical frontier. And it has also opened a new frontier in medicine--indeed, a fascinating one. This new branch of medicine, or more specifically of aviation medicine, is space medicine. Again Aesculapius extends his realm beyond the atmosphere into space and even into the areas of Venus and Mars.

Space medicine, which did not exist 8 years ago, is now well established. In 1949, General Harry G. Armstrong, then Commandant of the

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*Luncheon speech given at the Meeting of the Texas Academy of Internal Medicine, 10 Dec 1955.

School of Aviation Medicine, founded the Department of Space Medicine. At about the same time, at the Aeromedical Laboratory at Wright-Patterson Field, Ohio (General E. J. Kendricks, Commandant), the preparation of physiological animal experiments began. The Air Force has, since 1951, maintained a space-biological field laboratory at Holloman Air Force Base, New Mexico. The Soviet Union has an organization called the Institute for Astrobiology.

The first symposium on space medical problems was called by General Armstrong at the Air Force School of Aviation Medicine, Randolph Field, Texas, in 1948. Other symposia soon followed.

At a meeting of the Aeromedical Association held at Chicago, Illinois, in 1950, a branch of that organization was created and is known as the "Space Medicine Association." Since 1952 this association has held regular sessions each year--during the annual meeting of the Aeromedical Association, presenting a special program of its own.

Space medical topics have begun to appear on the programs of various related technical societies. Such societies--called space research societies, rocket societies, astronautical societies, and interplanetary societies--are found in 18 countries. These national organizations are all members of the International Astronautical Federation.

So much for the general and historical background of spaceflight and space medicine.

Before we enter into the discussion of the specific problems of spaceflight medicine, a point must be made clear. When the concept of flight first became associated with the word "space," it did so under the name of "space travel." This magic phrase intrigued the public, who immediately visualized trips to the Moon or Mars.

The word "travel" usually refers to long distances. According to Webster, travel means a "journey to distant and unfamiliar places" and generally covers weeks, months, or years. For trips to distant and unfamiliar planetary bodies, "space travel" indeed is the appropriate term. The full realization of this final goal, however, will probably take the course of a step-by-step evolution. For the preliminary stages, which we will discuss later, "spaceflight" is a more suitable term because flight may refer to a trip of short or long duration. How remote space travel may be is difficult to say. But spaceflight for the last few years has been, in a certain sense, a reality. Without a doubt we have trespassed its threshold. This fact becomes particularly obvious when we consider the medical problems encountered in the most extreme flights achieved today, and in those which will be made tomorrow. It is, therefore, primarily spaceflight which we have in mind when we discuss the problems of space medicine in the present stage of development. Incidently, however, the medical problems involved in space travel are, by and large, basically the same as in spaceflight.

SPACE MEDICINE - THE YOUNGEST OFFSPRING OF AESCULAPIUS

There are numerous medical problems involved in spaceflight; however, because of lack of time I shall confine myself to the problems arising from the environmental conditions in the new milieu, space, and from the motion conditions in this environment; and to the question "where above Earth's surface do these conditions begin?" They are impressive enough to convince us that we have entered a novel revolutionary phase in the development of human flight.

From the standpoint of astrophysics, the borderline between atmosphere and space can be drawn at an altitude of 1000 km (600 mi). At this level the collisions between the air molecules or atoms cease to occur; this means that here the atmosphere terminates as a material continuum, and in the form of a spray zone of free-moving particles, thins out into the near vacuum of interplanetary space. Here the particle density is $1/cm^3$ as compared with several quintillion per cm^3 in the atmosphere near sea level. From the standpoint of manned flight, it is not the material extension of the atmosphere that counts; rather, it is the cessation of the functions that the atmosphere offers for the process of flight. These functions--as we will see later--are manifold; but, and this is important, they do not terminate at the material limit of 1000 km--rather, they come to an end much lower and at different altitudes, some even well within the stratosphere. The levels where the various atmospheric functions cease are called the functional borders, or limits, of the atmosphere. At and above these functional borders we encounter, still within the atmosphere, spacelike or space-equivalent conditions with regard to the factor in question. Both of these concepts, functional border and space equivalence, are extremely useful to demonstrate how far we have advanced in the development of spaceflight.

From the standpoint of manned flight, the functions of the atmosphere by and large can be divided into three principal categories: life-sustaining climatic functions, life-protecting filter functions, and flight-supporting aerodynamic functions. In the following discussion, we shall subdivide these general basic atmospheric functions more into detail, contrast them with the conditions found in space, and examine where they terminate and where the space conditions set in. We arrive then at the following most important 10 specific points:

1. The Atmosphere. With its rather high concentration of oxygen, the atmosphere provides us with this vital bioelement for respiration; in space there is no oxygen. This atmospheric function comes to an end at 15 km (50,000 ft). At first this seems strange, because up to 115 km (70 mi) the atmosphere contains free biatomic oxygen, the kind we use in respiration. The reason for this lies in the fact that an airbody of about 2 liters is interposed between the external atmosphere and the "mitren enterieur" of our body. This airbody, the alveolar air, constantly maintains a rather high content of carbon dioxide and water vapor, both issuing from the body itself. Their combined pressures amount to about 87 mm Hg. As soon as, with increasing altitude, the barometric pressure

drops to 87 mm Hg, the influx of oxygen into the lungs from outside becomes impossible because the alveoli are already occupied to the full barometric pressure of the atmosphere by carbon dioxide and water vapor, both issuing from within the body itself. The air pressure of 87 mm Hg corresponds to an altitude of about 15 km. Above this level, therefore, we are beyond the atmospheric range that supports respiration. Insofar as the supply of oxygen to the body is concerned, we encounter the same situation as exists in free space. Hence, it is here that we meet the first of the vital functional borders (limits) of the atmosphere, or space-equivalent levels within the atmosphere. From the standpoint of medical terminology, this is the dividing line between hypoxia and anoxia in high altitudes.

2. Barometric Pressure. The atmosphere exerts upon us sufficient barometric pressure to maintain our body fluids in the liquid state and prevent them from passing into the vapor phase or boiling; in space no barometric pressure exists. This atmospheric function ceases as soon as the barometric pressure decreases to the vapor pressure of our body fluids. The water vapor pressure of our body fluids at normal body temperature is about 47 mm Hg. We can expect, therefore, that as soon as the barometric pressure drops to 47 mm Hg or below, our body fluids will boil. Experiments on warm-blooded animals in a low-pressure chamber, carried out as early as 1935 by H. G. Armstrong, showed this to be true. This boiling effect is first manifested by the appearance of gas bubbles in the superficial mucous membranes; later these bubbles appear in the subdermal tissue and produce a kind of vapor emphysema in the veins; and finally, they can be seen in the arteries, depending upon the different pressures in these areas or systems. The intrapleural spaces are filled with water vapor--a phenomenon which was called a vapo thorax by F. A. Hitchcock. There are still a number of questions open in this new field of vacuum pathology. Of particular note is the difference between low pressure-low temperature boiling (as found in high altitudes) and the process of boiling (used as a method of preparing food) that includes coagulation of the proteins--which must not be overlooked.

An air pressure of 47 mm Hg is found at 19 km (63,000 ft); above this altitude we lose the vitally important protection of air pressure against this so-called boiling, just as if we were surrounded by no atmosphere at all, as in space. This is the second functional border of the atmosphere, or space-equivalent level within the atmosphere.

Both of the space-equivalent conditions just discussed are impressive enough to convince us that we have entered a strange and completely novel environment. Here we face the anoxic phase and the vapor phase of high-altitude effect. These two facts justify the statement that a flyer entering this region above 19 km must be considered--from a purely physiological point of view--in space, since the physiological effects upon his body are practically the same as those he would find in the near-vacuum between the planets.

Both of these conditions lead us to a third atmospheric function in manned flight:

3. Necessity for a Sealed Cabin. Up to a certain altitude the atmosphere can be used for pressurization of the cabin to protect the flyer against the effects of decreased oxygen pressure and air pressure. In the emptiness of space, no ambient air is available.

For people to remain alive in space, they must be placed in a type of cabin in which an adequate atmosphere is artificially created and controlled, independent of the surrounding environment. Such a cabin is the so-called sealed cabin. The sealed cabin is a hermetically closed ecological system in which the life-sustaining components of the air are taken along from the start. The oxygen consumed must be replaced from storage tanks within the ship in such a way that it does not fall below the permissible minimum of 100 mm Hg nor exceed the permissible maximum of 350 mm Hg. Also, the expired carbon dioxide must be kept within the range of tolerance. (At this point I would like to mention that there are studies concerning the use of plants--for instance, of algae--as a photosynthetic gas exchanger for both oxygen production and carbon dioxide removal.) Furthermore, humidity, temperature, and barometric pressure must be controlled. The Air Force School of Aviation Medicine at Randolph Field now has an experimental sealed chamber in which we can study all these factors and the means to control them.

This type of cabin is the one that will be built in future spaceships. But it must be emphasized that such a spacecabin is required even at an altitude of 21-25 km (70,000-80,000 ft). Below this level we use the ambient air for the pressurization of the cabin. In the region of 21 km, however, the air is already quite rarified. To compress this thin air to physiological levels would be technically difficult, and the compressed air would become intolerable for the occupants. For all these reasons the conventional pressurized cabin as found in all military high-altitude planes and commercial airlines of today, has its altitude limits, and above 21 km must be replaced by the sealed cabin. This cabin has no limitations on altitude whatever. It gives us the green light into space.

The altitude at which a hermetic cabin becomes a necessity represents another space-equivalent condition, from a biological point of view as well as from a technical one. Above this level the cabin has no life-sustaining contact with Earth's atmosphere. It is a world all its own, a little Earth--a terrella with its own atmosphere and a population of 2, 3, or 4.

The space-equivalent conditions which we have discussed so far are brought about by the loss of genuine properties of Earth's atmosphere. However, with increasing altitude, extraterrestrial factors enter the picture to a greater extent. Finally, they create space-equivalent conditions of their own still within the atmosphere, as it is astronomically defined. This group of space-equivalent conditions is related to the filter function of the atmosphere.

This atmospheric function is of greatest import with regard to radiation of cosmic and solar origin.

4. Cosmic Rays. In the lower zones of the atmosphere we are protected against cosmic rays by the filter function of the atmosphere. In space no such natural protection can be expected.

Cosmic rays, in their space form, consist of up to 79% protons or hydrogen nuclei, 20% alpha particles or helium nuclei, and 1% nuclei of heavier atoms up to those of iron. They have an extremely high kinetic energy which they may have attained by acceleration in magnetic fields between galaxies and interstellar clouds.

When the primary cosmic rays enter the atmosphere, from a certain density level on, they lose their original powerful form in ionizations of air molecules and atoms and in the production of so-called explosion stars when they collide with the nucleus of an atom. These processes of absorption take place between 37 and 18 km (120,000-60,000 ft). The ionization and collision products--protons, electrons, neutrons, mesons, and gamma rays--rain down, sometimes in showers, through the lower layers of the atmosphere. These secondary rays, which were discovered by V. Hess, 1908, during balloon ascents, are less powerful than the primaries but powerful enough to penetrate several hundred feet into the water. So, at sea level and up to 18 km we are exposed only to these secondary and tertiary cosmic rays. Above 37 km, however, we will be exposed to the more powerful bombardment of the original primaries. Here we are beyond the protecting shield of the atmosphere, as in space or as we would be on the Moon which has no atmosphere. This is the fourth space-equivalent level within the atmosphere, or the first with regard to the atmospheric filter function. At the present time intensive studies concerning the biological effect of cosmic rays are under way in Holloman Air Force Base, in balloons flying at 30.5 km (100,000 ft) high for several days.

5. Ultraviolet of Solar Radiation. Of some biological interest also is the erythema or sunburn-producing ultraviolet of solar radiation. Its band lies between 2100 and 3000 Å. Most of these rays are absorbed by the ozone of the atmosphere. We are, therefore, protected against their effects at sea level and moderate altitudes. We live in the shadow of ozone. The atmospheric ozone is concentrated mainly in the area of 21-43 km (70,000-140,000 ft) (ozonosphere). This means that above the 43-km level we are beyond the ozonospheric umbrella of the atmosphere and that we are exposed to the full force of ultraviolet--again, a spacelike condition within the atmosphere with regard to this factor. Ultraviolet rays should, however, present no serious problem since the hull of the ship protects the crew sufficiently.

6. Scattering of Light. We now proceed to the visible part of the electromagnetic spectrum of solar radiation. An important factor in atmospheric optics is the scattering of light by the air molecules. This scattering effect of the atmosphere produces the so-called skylight; and because the short-wave part of the visible spectrum is especially affected by this process, the sky appears blue to us. With increasing rarification of the air molecules in higher altitudes, however, scattering of light decreases more and more and the blue sky gradually turns into the mysterious darkness of space. This optical space-equivalent condition is reached in the area of 130 km (80 mi).

Essentially, it is the lack of scattering that makes space optics so different from atmospheric optics. In space the sky brightness is lower but solar illumination is higher than within the lower atmosphere. This means that against a background of low field brightness, any object illuminated by the Sun appears extremely bright. Light and shadow dominate the scenery. This photoscotic condition, which is encountered in full display at about a 130-km altitude, poses interesting visual problems in the field of contrast vision and retinal adaptation.

7. Propagation of Sound. At about this same altitude, propagation of sound becomes impossible. Sound propagation requires a certain density of the air. But as soon as the free pathway of air molecules is in the order of the wavelength of sound, transmission of sound ceases. The region where this occurs lies between 80 and 160 km (50-100 mi). Above 160 km the silence of space begins. In this thin atmospheric medium no shock waves can be produced at any speed; therefore, there is no sound barrier and the unit of Mach number becomes meaningless.

8. Occurrence of Meteorites. The most spectacular of extraterrestrial factors are meteorites. Between 40 and 120 km (25-75 mi) above Earth, most of these meteorites are burned out by friction with the atmosphere. Above 120 km a rocket ship is beyond the "meteor safe wall" of the atmosphere, unprotected as in space. The probability of colliding with a meteorite, fortunately, is rather remote, even beyond the 120-km level. Furthermore, suggestions have been made for protection by so-called meteor bumpers consisting of an outer layer of steel to absorb the impact of the meteorite.

All of the problems which I have enumerated so far would arise if we considered a vehicle in this environment at rest or floating--if this were possible. The respective space-equivalent conditions are more or less topographically or locally fixed at certain altitude levels, conditioned by the milieu as such, and therefore may be called local space-equivalent conditions.

9. Weightlessness. One important space condition occurs in flight as a direct result of the vehicle's movement. This is the phenomenon of weightlessness. In the atmosphere a moving craft is supported by the air aerodynamically. In airless space no such support can be expected.

If a body, however, has no support, it cannot exert weight--or it is weightless. The flight-supporting function of the atmosphere ceases at about 195 km (120 mi) for any speed. Above this level we can produce weightlessness for any length of time. Actually, weightlessness in flight is produced when centrifugal forces, caused by the vehicle's inertia, balance the gravitational force of Earth. These forces replace the support by air and keep a vehicle flying. In a horizontal flight, which is actually a gradual curve around Earth, a speed of 29,000 km (18,000 mi) is required to balance the gravitational force. This is the so-called orbital velocity, or the speed required for an artificial satellite. Within the atmosphere we can produce the gravity-free state for 30 seconds in jets, or for several minutes in rockets when they fly a vertex of an elliptic or parabolic orbit. In brief, weightlessness in flight is the result of motion. It has nothing to do with a certain location within the gravitational field of Earth. It is a matter of dynamics. Weightlessness, therefore, is--insofar as it occurs within the atmosphere--a dynamic or kinetic space-equivalent condition. It is independent of the distance from Earth; only its duration is dependent on the air's density and consequently on the height. The altitude level of 195 km, where permanence of zero gravity is conceivable, can be called the aerodynamic border of the atmosphere. A number of theoretical papers have been written and experiments carried out on the physiological effect of zero gravity. It is still too early to state whether zero gravity is a serious medical problem or merely an interesting psychophysiological phenomenon. We now come to the last of our ten points.

10. Heat Transfer. The atmosphere contains, conducts, and transfers heat. In space the carrier and transmitter of heat is exclusively solar radiation. A vehicle flying within the atmosphere with supersonic or even hypersonic speed, produces heat by friction with the air molecules: the so-called heat barrier. But again, at about 195 km the transfer of heat produced is negligible because of the rarification of the air. Above this level we encounter frictionless movement, as in space, and from here on the temperature of the cabin's hull is governed solely by solar radiation. Under this aspect we call the 195-km level the aerothermodynamic border of the atmosphere.

This 10-point discussion demonstrates clearly the drastic environmental differences between the atmosphere and space; it also shows that there is a broad transition zone between the two. We have seen that, from the standpoint of manned flight, the largest, upper portion of the atmosphere shows conditions typical of interplanetary space. The area in which we encounter one, two or more, but not yet all factors typical of space, must be considered as partially space-equivalent. This begins at 15 km (50,000 ft). The area above 195 km is distinguished by total space equivalence if we ignore some variations caused by the bulk of Earth itself, its magnetic field, its speed, and its own and reflected radiation. For the flyer the atmosphere beyond 195 km is no more tangible, it is imperceptible. Here the atmosphere turns into a pseudoatmosphere. This pseudoatmosphere is no more effective aerodynamically nor aerothermodynamically. The 195-km level is, therefore, the flight-effective limit, or the final functional limit, of the atmosphere. Beyond this functional limit the laws of astrodynamics dominate the field. This dividing line between aeronautics and astronautics is the altitude where the nearest orbit of an artificial satellite is conceivable.

Today's manned rocket-powered craft have already advanced well into the area of partial space equivalence, passing beyond at least three important space-equivalent levels. Animal-carrying rockets have left nearly all of them behind. Unmanned two-stage rockets have penetrated deep into the area of total space equivalence.

From the standpoint of the environment and of the movement in this environment, we are, at present, in the partial space-equivalent phase of manned flight.

This is the first phase in spaceflight. It might be appropriate to add a few remarks about the possible future development of manned flight and spaceflight. Such an attempt to classify the possible stages of spaceflight can be based on three factors: the environment, the destination of the flight, and especially the factor of speed. In so doing we see an evolutionary course of development of manned flight that looks somewhat as follows:

The long-distance flights of today take us at subsonic speed, under normal gravitational conditions, in pressurized cabins through the lower regions of the atmosphere, from one point on the globe to another distant point on the globe--across a number of time zones and/or across zones of different seasons--in a single day. These are global flights. This epoch in flying began when Charles Lindbergh first crossed the Atlantic.

We are now on the threshold of the next stage. In that epoch, rocket-powered planes will take us at supersonic speed or even hypersonic speed, under subgravitational conditions, in a sealed cabin through the space-equivalent regions of the atmosphere, from one point on the globe to another even more distant point on the globe in a matter of a few hours. We stay on the globe but fly under space-equivalent conditions. As far as gravitation is concerned, the craft moves partially under airplane conditions and partially under ballistic conditions like a bullet; which means that the craft attains projectile status. These hypersonic long-distance flights will fall into the category of global space-equivalent flight.

As soon as the circular orbital velocity (8 km or 5 mi/sec) has been reached, flights of long duration around the globe in a satellite orbit under conditions of zero gravity and in an environment equivalent to space, will be possible. The vehicle now attains satellite status.

But these craft will still operate within the gravitational control of Earth and will remain within Earth's vicinity. This eventual stage may be called circumglobal or circumterrestrial spaceflight.

The next step will follow after the so-called escape velocity (11 km or 7 mi/sec) has been reached. At this speed the vehicle breaks away from the gravitational control of Earth and escapes in interplanetary space. This, then, will be interplanetary spaceflight, or what we can call "space travel."

This classification gives us, I believe, a clearly defined and realistic picture of the stage at which we stand today and of the possibilities we may expect in the future. At present we are actually in the first phase of spaceflight; namely, global space-equivalent flight. Solution of the medical problems in this stage is, therefore, of immediate concern to the physiologist, the engineer, and the flyer.

Such is the picture that can be portrayed today about spaceflight and the medical aspects involved. Space medicine will play an important role. What makes space medicine so fascinating is the fact that not only is it associated with scientific fields that deal with terrestrial atmospheric matters such as meteorology and aerodynamics, but that it is also linked with scientific fields that deal with matters of extraterrestrial nature like astronomy, astrophysics, and celestial mechanics, or astrodynamics. These associations reflect specific and novel missions of this branch of medicine. And the methods applied in research are unique. The outstanding ones are research rockets like the Viking and the method of telemetering.

I would like to conclude that even if spaceflight were never realized, studies of this kind with an extraterrestrial trend might be very valuable. The study of the cosmic rays has already contributed to our knowledge in general radiology. Eliminating gravity might increase our knowledge about the coordination of reflexes under normal gravitational conditions, just as the experimental elimination of vitamins in the food brought about the recognition of vitamins and their function. So, I hope that space medicine will not only make its contribution to spaceflight, but also to medicine in general.

IMPACT OF SPACE MEDICINE ON FUTURE MEDICINE*

Hubertus Strughold, M.D., Ph.D.

I feel very honored to be here with you in Arizona, my favorite State, to discuss the impact of space medicine upon future medicine. To get a better understanding of this question, let's first briefly remember the various influences of certain discoveries, or inventions, upon medicine in its modern history; i.e., during the past 400 years.

The first decisive step to a modern scientific medicine was the invention of the microscope at the end of the 17th century, which revealed that the basic anatomical element of life is the cell. This realization found its climax--200 years later--in the development of cellular pathology.

A second important event was Lavoisier's discovery--at the end of the 18th century--that oxidation is the basic physiologic metabolic life process. This knowledge revealed the true nature of respiration which, up to that time, was explained by Erasistratus' pneuma and later the phlogiston theory. From a biochemical point of view the molecular phase in medical thinking now began, as evidenced by the increasing activity in respiratory and metabolic research.

At the end of the last century, Antoine Henry Becquerel's discovery of radioactivity and Wilhelm Roentgen's demonstration that certain rays can penetrate material proved that Democritus' concept of the atom as the smallest individual particle was wrong. The subsequent discovery of the various subatomic particles and, finally, the experimental splitting of the atom into its particles opened the atomic age, which is represented in a nuclear branch of medicine.

Such has been the development of some basic aspects--cellular, molecular, and nuclear--in the history of medicine and biology as the result of important steps in the advancement of physical sciences and technology.

Almost simultaneously with the atomic age a technologic development set in, which made it possible that an old dream of mankind became true. Man learned to fly. With the development of aeronautics he became airborne. This placed man in a novel environmental situation. Whereas movement of man on Earth's surface--be it by foot, horse, camel, railroad, automobile, or ship--was exclusively two-dimensional; now, with the

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appearance of the airplane it became, to a certain extent, three-dimensional. This additional third, or vertical, dimensional component leading into higher altitudes required special medical attention.

Medicine as an environmental discipline developed an air arm known under the name "Aeromedicine," or "Aviation Medicine," to make atmospheric flight safe and efficient. There is no question that this aerial branch of medicine has not only served its specific purpose, it has also made important contributions to physiology and medicine in general. For instance, if we have today a better understanding of the various types and effects of oxygen deficiency; the interrelation between blood, respiration, and circulation; the role of carbon dioxide in respiration, etc., it is due to the successful aeromedical research carried out during the past 30 years. But airplanes possess air-breathing engines and have, therefore, altitude limitations. This dependency upon the atmosphere has been broken by a new technologic development, the rocket. This propulsion device does not need atmospheric oxygen for fuel combustion; it carries its own oxidizer, or may some day utilize nuclear power. This self-sufficiency enables the rocket to fly beyond the atmosphere into the new vacuum of space; furthermore, its powerful thrust exceeds by far all other propulsion devices and makes it even possible to break away from Earth's gravisphere and to reach the distances of other celestial bodies. This is the beginning of the Space Age.

A few moment's ago I mentioned the third dimension. The vertical component is actually only an indication of it in atmospheric flight; namely, during the ascent and descent of the airplane, representing merely a vertical shift of the horizontal level between the ground and the operational flight level. We can really say that only the rocket has truly conquered the third dimension or opened the vertical frontier.

In atmospheric flight, therefore, man always remains, somehow, under the protection of the surrounding air. Along the vertical rocket trajectory, after a few minutes the atmosphere is left behind. Spaceflight, therefore, is distinguished by complete absence of an atmospheric medium, and the atmospheres on other celestial bodies are qualitatively and quantitatively different from ours.

To provide the means for man's survival in such environments puts medicine really on the spot. Now in addition to its air arm, medicine has developed a space arm. Space medicine, as this new addition to medicine is called, officially came into existence 10 years ago with the foundation of a special Department of Space Medicine. Today it is recognized as an indispensable, vital part of the science and art of spaceflight, or astronautics. In fact, in the present international space race, after the two fundamental astronautical velocities (orbital and escape velocities) have been achieved with unmanned vehicles, the accent has shifted from space technology to space medicine as far as the achievement of further historical events is concerned. I think we can be very proud that our profession plays now such a decisive role in the National Space Program.

But it is not the purpose of this discussion to elaborate on the role of space medicine in man's conquest of space; instead, I would like to talk about the impact of space medical research upon future medicine in general, which familiarizes us with some of the space medical problems as well. This effect is twofold; first, it increases our knowledge about the physical environment on Earth in which we live and its medical implications; and, secondly, it will have some influence upon the future development of medical instrumentation.

The environmental factor is one of the focal points in space-medical research. During a spaceflight trajectory--during the process of movement to, through, and return from the environment of space, a wide range of variations in the G-pattern is experienced in a most acute form. During launching, a man in a space vehicle is exposed to increased G's for several minutes, followed by zero G for any length of time, depending on atmospheric reentry, which again imposes an even heavier G-load upon the returning astronaut.

The effect of increased G, which manifests itself in increased weight, has been studied for more than 20 years on large centrifuges and rocket-powered sleds, and effective protective measures have been found in the development of anti-G suits and by placing the man in such a position that the G-forces act upon him vertically to his longitudinal body axis. The application of this knowledge to actual rocket flight will keep increased G's in tolerable limits. The results of the studies about increased G, especially those of P. Stapp during sudden deceleration on rocket-powered sleds, are also very valuable in the analysis of automobile accidents.

What about the zero-G phase of the spaceflight trajectory, during which the astronaut has no weight at all? Thousands of so-called parabolic flight maneuvers in jet planes have shown that most of the pilots could handle the state of weightlessness for a minute or so, and monkeys and dogs in suborbital rocket flights which lasted several minutes; and the Russian dog, Laika, in orbital flight seemed to be not too much disturbed by weightlessness. The final answer concerning longer durations of zero-G, of course, has to come from the first orbiting astronaut.

ANATOMY OF SPACE:
PHYSIOLOGICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

Space is usually thought of as empty, or as a vacuum. This is true when we compare it with the barometric pressure conditions found in the lower, denser layers of our atmosphere where the air pressure reaches an average value of 760 mm Hg. The lowest pressures used in the laboratory are in the order of 10^{-6} to 10^{-7} mm Hg. Such low pressures are found, for instance, in electronic vacuum tubes, but the gas pressure in space is immeasurably small and can be estimated to be in the order of 10^{-16} mm Hg, because there are not more than 10 gas molecules in 1 cm^3, as compared with tens of quintillions of gas molecules in 1 cm^3 of air at sea level. In 1,000 cubic miles of space there are not more gas particles than in a thimble full of air at the Earth's surface. So considered, space is indeed a vacuum. But space is not empty. There are contents of a material and energetic nature in the environment of space, most of which pose physiological hazards to spaceflight; some, however, can be made useful.

These space contents are not evenly distributed throughout the solar system; rather they show regional variations which represent zones of decreased or increased hazards, or even set definite physiological limitations to spaceflight. Moreover, these regional variations may show temporal fluctuations resulting in periods of increased danger. In the following, therefore, I shall discuss the environment of space, with special emphasis on the regional and temporal variations, considered from a physiological or ecological point of view; in other words, their space medical implications.

Beginning with the material contents of larger dimensions, there are the meteorites from the size of large lumps of matter to micrometeorites as small as white blood cells, crisscrossing space with an average velocity of 25 miles per minute at the orbital distance of the Earth. Their overall frequency distribution increases with decreasing size. Recordings of micrometeorites in the Explorer satellites have already considerably improved our knowledge in this respect. There are noteworthy regional differences in the distribution of meteoric material and its velocity. Near Earth a space vehicle is shielded by the planet's solid body over a large solid angle; on the other hand, Earth's gravitation increases the velocity of the attracted meteorites at small distances from Earth.

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Secondly, the meteoric material is essentially found in the plane of the ecliptic. Therein it is specifically concentrated in the form of streams along the orbits of disintegrated comets, of which most meteorites are remnants. Their frequency may also be greater within the belt of the asteroids, a second source of the origin of meteorites. The velocity of meteorites is higher the nearer they are to the Sun.

Now, the space medical implications of meteorites are obvious. The effects of a collision with meteoric material are twofold: puncture and surface erosion. A puncture of the skin of the space vehicle by a meteorite with a diameter of a few millimeters or more can lead to rapid decompression of the cabin's air, with all the ensuing physiological consequences for the astronauts--anoxia, aeroembolism, boiling of the body fluids, or ebullism. In such an emergency the time of useful consciousness of the crew may offer a chance to seal the leak. Also, suggestions have been made for protection in the form of self-sealing devices and of a secondary hull (a so-called meteor bumper) surrounding the cabin to break down and disperse the colliding meteoric body into fine dust (F. Whipple).

Erosive effects of fine meteoric material on surfaces exposed to space may affect the transparency of windows, the characteristics of heat-absorbing and reflecting surfaces, and the antennas. The same may be said of dust particles found in space with a frequency of about one particle per 10 m^3. All this demands the engineer's attention in the design of the vehicle.

Of less ecological importance are the gas particles found in numbers of about 10 in 1 cm^3, and consisting mostly of hydrogen. In the region of the inner portion of the solar space they are ionized by the ultraviolet part of the solar radiation; consequently, electrons in numbers of about 10 to 100 per 1 cm^3 are also found in these regions. Electrically charged gaseous material is called plasma. Thus, the environment of space is a very thin plasmatic medium.

An extremely important material component in space are charged atomic particles completely stripped of their electrons and moving with very high kinetic energy, some approaching the speed of light. They are called cosmic rays and consist mostly of nuclei of hydrogen (protons) and other atomic nuclei up to the ion group. The origin of the cosmic radiation has not yet been entirely clarified. Most of it probably comes from somewhere in the galaxies. Sometimes cosmic rays are ejected from the Sun, especially during flares and eruptions, which also blow large amounts of ionized material deep into space in the form of jet streams and clouds of solar plasma. In interplanetary space, generally an omnidirectional flux of these corpuscular rays is prevalent. But again there are regional and temporal variations.

We encounter the primary cosmic ray particles as low as 120,000 feet, but there they come into collision with the atmospheric molecules and are transformed into secondary and tertiary rays to which we are normally exposed. Near Earth a space vehicle is protected from the primary cosmic rays from below by the shielding solid body of the Earth, just as it is in the case with meteorites, as already mentioned.

The most remarkable regional variation is the recently found concentration of energetic particles trapped by the geomagnetic field in the form of a huge radiation belt, consisting of two zones, discovered by means of the Explorer satellites in 1958 by J. Van Allen. The inner zone extends from about 500 miles to 4,000 miles. It contains trapped electrons and protons of high energy, which are produced by beta decay of cosmic ray neutrons scattered outward from the fringe regions of the atmosphere. The outer zone of the Van Allen belt consists also of electrons and protons, but they have lower energies. They come directly from the Sun and are somehow deflected and then trapped by the magnetic field lines. This zone extends from 8,000 miles to about 60,000 miles.

The existence of this great radiation belt poses a serious problem to manned spaceflight. Although at this time the exact topographical intensity pattern is not known, this much can be said--that both of these zones will be prohibitive for manned satellite flight unless heavy shielding can be used. The relatively safe region for this type of spaceflight will probably not extend beyond 500 miles above the Earth's surface. Whether or not satellite orbits in the slot between the two belts (from about 4,000 to 8,000 miles) are medically permissible requires further exploration.

In these, as well as other more extended space operations, protective measures must be considered. They are: avoiding the danger zones by choosing the polar regions as exit and reentry routes, higher velocities to shorten the time of exposure and shielding, or a combination of them. This is an important problem that will occupy astrophysics, space technology, and space medicine in the coming years. The same is true concerning the possible occurrence of similar radiation belts surrounding other celestial bodies, such as Venus and Mars. These localized concentrations of corpuscular radiation seem to be more important from the standpoint of radiation hazards than the more or less evenly distributed omnidirectional cosmic rays, including their heavy components.

The next and final environmental factor in space is solar electromagnetic radiation, which includes the range from soft x-rays of about 10 ångstrom, ultraviolet rays, visible rays, and infrared rays to radio waves of more than 10-m wavelength. Not very much is known about x-rays in space; ultraviolet is no problem because the astronaut is sufficiently protected from these rays by the vehicle and his equipment. Of special importance are the visible and the heat-producing portions of the solar electromagnetic spectrum. Since radiation varies with the inverse square of the distance from the radiating source, the variations within the solar space are enormous and differ tremendously from the value found at the Earth's mean orbital distance, which we shall use as a baseline. Light irradiation from the Sun or solar illuminance above the Earth's atmosphere amounts to roughly 140,000 lux, i.e., lumens per square meter. For comparison, on Earth's surface the corresponding value is never higher than a little over 100,000 lux, not even at such sunny places as Florida and Texas. An illuminance equaling the maximal terrestrial surface value is found in space at a distance of some 20 million miles further from the Sun; that is about halfway to Mars. At the mean orbital distance of Mars the illuminance drops to 60,000 lux; at that of Jupiter, to 5,000 lux; and in the remote region of Pluto, below 100 lux. In the direction toward the Sun, at the orbital distance of Venus, solar illuminance increases to 267,000 lux, and at the solar distance of Mercury, to nearly 1 million lux.

This great range of variations has significance in two respects: with regard to vision and with regard to the utilization of light in photosynthetic recycling of metabolic material in the closed ecological system of the space cabin.

Beginning with the latter, there is no question that solar illuminance drops with increasing distance below the minimum required for photosynthesis, and this limit is reached somewhere beyond Saturn. Beyond this distance a spaceship would have to provide its own light energy. For this purpose a nuclear powerplant would have to replace the Sun.

As for vision, solar illuminance is the decisive factor in the visual panorama of space; another is the absence of an effective light-scattering gaseous medium, which results in a permanent dark or even black sky, despite a bright shining Sun. This combination leads to a strange optical situation found on Earth only under artificial conditions; for instance, in theatrical stage lighting. Everything that is exposed to sunlight appears extremely bright--everything in the shadow is black. Light and shadow dominate the scenery. This photoscopic condition poses interesting problems in the field of contrast vision and retinal adaptation, and requires special attention in the design of the space cabin windows.

By looking into the Sun with the naked eye retinal damages such as retinitis solaris and retinal burns may result in a blind spot in the visual field (helioscotoma). Retinal lesions of this kind occur on Earth frequently when a solar eclipse is observed without sufficiently smoked glasses (scotoma helieclipticum). Outside of the Earth's atmosphere and on the airless Moon, the danger is much greater and increases, of course, in a heliopetal direction, as for instance on an expedition to Venus. Caution in this respect is indicated, and eye protection by means of light-absorbing glasses is a necessity. Where, in space, the retina-burning power of the Sun becomes negligible is difficult to extrapolate from experimental data obtained on rabbits concerning similar retinal lesions caused by atomic flashes; it may be somewhere beyond Jupiter. Such retinal lesions are actually heat effects by visible rays and the neighboring near-infrared rays, focused by the eye's lens upon a small area in the fovea centralis retinae and producing a thermal necrosis with a subsequent scar.

With this we have already touched upon heat radiation in space.

The intensity of heat-carrying rays (essentially visible and infrared) is measured by the amount of heat irradiated upon a unit of area per unit of time, and is conventionally expressed in calories per square centimeter and minute. At the top of the Earth's atmosphere the value of the heat flux from the Sun is roughly 2 cal/($cm^2 \cdot min$). This is called the solar constant. On the Earth's surface, at noon under favorable weather conditions, thermal irradiance is never higher than two-thirds of this value because of reflection of the radiation back into space and heat absorption by atmospheric water vapor and carbon dioxide. Using the terrestrial solar constant as a baseline, the thermal irradiance at the orbital distance of Venus increases to nearly double; at the mean orbital distance of Mercury it is more than six times as high. At the distance of Mars it decreases to less than one-half; at Jupiter's distance, to one twenty-seventh, and in the remote region of Pluto it drops to one sixteen-hundredth of the terrestrial value.

The space medical conclusions from these extreme variations are these: It makes a great difference concerning cabin temperature control whether a space operation is planned into the furnace-like heat-radiation condition beyond Venus or into the deep-freeze environment beyond Jupiter. Actually, there are even definite limitations. Somewhere in the region beyond Mercury a spaceship would inevitably run into a kind of solar-heat barrier, as symbolized by the legendary flight of Icarus.

What we have tried to do in this discussion was to examine the physical contents of space which are essentially molecular, atomic, and nuclear particles, and energy quanta. In terms of medical thinking, this is a kind of microscopic anatomy of space. We took special notice of the fact that they are unevenly distributed over large areas. This leads, logically, to a macroscopic topographic approach, to a topographic anatomy of space. The results of the Geophysical Year, and thereafter, have shown that a dissection or subdivision of space is possible and that it is even necessary in the interest of safety in astronautics. To use a more conventional term, this is actually a kind of geography of space, or, briefly, spatiography.

How can we subdivide a giant pie which, spatially considered, consists of nothing?

First, we have seen that space in the vicinity of Earth is different from open interplanetary space. The difference is caused by the shielding function of its solid body from meteorites and cosmic rays.

Of spatial importance is the influence of the geomagnetic field on ray particles by forming a double-zoned radiation belt over the magnetic equator and causing the auroras by channeling them along the magnetic-field lines into the polar atmospheric regions. This whole volume of space, within which the influence of the Earth is distinctly recognizable, we might call nearby or circumterrestrial space, and may assume for it an extension of up to 14 earth radii or 60,000 miles, which is the outer boundary of the great radiation belt. Beyond this line we may speak of deep space, which blends at a distance of 1 million miles with interplanetary space. Here a space vehicle leaves the sphere of gravitational influence of the Earth, or the terrestrial gravisphere, and comes under the sole influence of the Sun. The interplanetary space, as we have seen, shows again enormous differences based on solar irradiance, both photic and thermal. But between the extremes there is a zone which differs not too much from our point of departure, the space at the Earth's solar distance. This relatively favorable ecological belt or ecosphere in the solar system, extending some 50 to 100 million miles in both directions from the Earth's orbit, will be the region to which manned space operations will probably be confined, at least in this century.

This is what we learn from a topographical anatomy of space, or ecological spatiography. Spatiography, of course, refers only to the space between the planets. The description of the ecological conditions on these celestial bodies is called planetography. Both spatiography and planetography are the two subdivisions of an all-embracing ecological cosmography of our solar system.

FUTURE PLANS IN SPACE MEDICAL RESEARCH*

Hubertus Strughold, M.D., Ph.D.

I feel very honored to give you a brief outline of some aspects of the research program of the future to be carried out at this Aerospace Medical Center. With this I have essentially in mind the task of an Advanced Studies Group, established here several months ago on the initiative of Major General Benson, to look into the future, i.e, to explore the future potentialities of manned flight and to develop theories of how to cope with the medicobiological problems involved, in order to speed up progress and to avoid devious projects in the overall National Space Program. Safety and performance efficiency of man's penetration of space are the business of medicine in this program.

This requires extensive knowledge of the ecology of the environment of space itself and of the ecological environmental qualities on the target celestial bodies, an examination of the safest and most effective routes for journeys to and from these celestial bodies, and the determination of favorable time schedules and optimal flight velocities.

Practically all factors in solar space are caused or influenced by the Sun as an emitter of plasmatic material; as the source of heat, light, and photochemical energy; and as the center of gravitational and magnetic forces. Of special interest is the effective extension of these various components of solar influence; for instance:

(1) The actual extension of the solar corona and how this may affect or set limitations to manned spaceflight. This needs clarification, especially since--according to Chapman-- even Earth moves probably in the fringe zone of the solar corona.

(2) Emission of solar plasma in the form of jet streams and how these increase the radiation hazards.

(3) Total solar electromagnetic irradiance, expressed in g cal/($cm^2 \cdot min$), and its significance for the temperature control of the cabin.

(4) Solar illuminance, expressed in lux (lumens/m^2), and how it affects the visual panorama in space, to what degree it may pose hazards to the human eye, and to what extent it may be utilized for

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*Briefing for the Committee on Science and Astronautics, Aerospace Medical Center, Brooks AFB, Texas, 17 Nov 1959.

photosynthetic recycling of metabolic end products in the closed ecological system of the spacecabin.

(5) Intensity of solar ultraviolet and X-rays in space.

(6) General distribution of meteorites and their regional concentrations in the form of meteor streams and swarms.

(7) Effects of meteorites and micrometeorites upon a vehicle, in the form of puncture, erosion, and sputtering, and prevention of the hazards connected therewith.

(8) General distribution of particle rays and their regional concentration in magnetic field.

(9) Effect of particle rays upon a space vehicle; how to block them, and how to reduce the secondary rays by various types of shielding to physiologically acceptable levels.

A successful and safe penetration of space by man makes necessary the development of an ecological space chart or map--a "geography" of space, or spatiography--with regard to all the physical factors which have a bearing on the safety of spaceflight.

The velocity of a space vehicle, however, may change the ecological picture of space. Present thinking in space technology is based on minimum-energy orbits. A flight to the Moon in this way takes 1.5 days. This is biotechnically feasible and medically acceptable. But a flight to Mars, by coasting, requires 9 months. Medically, this is hardly acceptable and, as long as an effective recycling system is not achieved, biochemically not conceivable. From the standpoint of bioastronautics, we must demand--recent experiences in spacecabin simulators suggest this--a minimum time orbit. This, of course, means an increase of the velocity by additional propulsion. The question is how much can the velocity be increased without the particle material, such as micrometeorites, dust, and atomic particles of the radiation category, becoming disastrous to the vehicle at impact. Compressing the time of a flight to Mars to one-half or one-third of the duration it takes in a minimum-energy orbit would be very desirable. Even then, we would have to concentrate our efforts upon new and more effective chemical and biochemical methods for recycling the environment in the spacecabin.

Additional propulsion, of course, involves slight acceleration. This brings up the question of zero gravity and subgravity. It may become important to know what fractions of 1 g are required to give the astronaut some feeling of weight and to bring about a normalization of life in the spacecabin in terms of gravity. If the coming orbital flights should indicate that zero gravity over longer periods of time leads to difficulties physiologically and biotechnically, we are interested in the rotation problem to provide the necessary amount of artificial gravitation.

These are some of the open questions related to the human factors involved in actual space operations.

The medicobiological problems encountered on the neighboring celestial bodies represent another area of our interest. They can be subdivided into two categories which, to a certain degree, overlap; namely, astromedical studies of the conditions on the target celestial bodies with regard to human physiology, and astrobiological studies that examine the question of indigenous life on these bodies. The Moon is our first research target. Mars and Venus are the next in line on the research program of the Advanced Studies Group of this Aerospace Medical Center.

The solution of most of these medicobiological problems encountered in space between the celestial bodies, on their surfaces, and in their atmospheres, depends strongly on aeromedical lines of thinking and experiences and requires, therefore, basically an aerospace medical approach.

SPACE MEDICINE AND ASTROBIOLOGY*

Hubertus Strughold, M.D., Ph.D.

The extraordinary nature of the problems with which the life sciences are faced in manned spaceflight is distinguished by the following features:

1. The environment in space is characterized by the absence of a life-supporting, life-protecting, and flight-supporting atmosphere.

2. To travel through such a vacuum environment requires a sealed cabin, a synthetic little Earth with an artificial atmosphere, surrounded by a hull having life-protecting capabilities with regard to radiations and meteorites.

3. The astronauts occupying this isolated island in space represent, psychologically, a world of their own.

4. The physical environments on the target celestial bodies are qualitatively and quantitatively different from that of the astronaut's home planet, Earth, and thus require special biotechnical measures for their survival.

5. The astronauts may discover on target celestial bodies another living world with strange, exotic flora and fauna, which may pose important problems of useful and harmful biotic interrelations, such as contamination.

6. During the larger part of the spaceflight trajectory, the vehicle itself behaves like a celestial body following the laws of celestial mechanics. This condition, the transformation of a vehicle from Earth into a celestial body (and its retransformation into an aerodynamic vehicle), and the gravities found on targets such as the Moon and Mars, subject the astronaut, who is basically a 1-g creature, to a large spectrum of g forces from zero g to multiples of 1 g.

These are in brief the striking novelties the life sciences are confronted with in this space age. For the life-sciences branch that is concerned with the human factor in spaceflight and on target

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celestial bodies, the term "space medicine," or "cosmic medicine," has come into use. Astrobiology is reserved to the field that studies the problem of indigenous life on other celestial bodies.

Now if medicine is the science and art of preserving and restoring health, space medicine is the science and art of preserving man's health in space. This is perhaps the greatest challenge to medicine in its entire history. By and large, the space medical problems arise from the environmental conditions outside the spacecabin; from those inside the cabin; from the process of movement of the vehicle to, through, and return from the environment of space, or, in brief, from its motion dynamics; and from factors inside man himself (his psychophysiologic nature). Some of these problems overlap; between some of them are interrelations. Most of them put space medicine into the category of environmental medicine. By cooperating with space technology in designing life-supporting equipment and preventing hazards on launching sites, space medicine also has the character of industrial medicine.

It is impossible to survey in this paper the whole complex scope of the space-medical problems; instead, I have to confine myself to some basic remarks, critical areas, present status, and future prospects of manned spaceflight.

It is the first task of space medicine to evaluate ecologically the environment of space in its basic structure, especially in its regional and temporal variations. This leads to a kind of ecological "geography" of space, more precisely called spatiography. Such a spatiographic study must include Earth's atmosphere in order to determine where above Earth's surface space actually begins.

From a medical point of view, the first 4000 m above Earth's surface represent the physiological atmosphere. The region from 4 to 7 km can be regarded as subcritical; from 7 km on, it is dangerous to life and therefore critical; the determining factors for both of these zones are hypoxia and anoxia. At 20 km a new pathophysiological effect, namely "boiling" of body fluids, or ebullism, enters the picture and makes the atmosphere a supercritical one because it produces the same pathological symptoms as a vacuum. For all practical purposes the atmosphere is now space-equivalent as far as its physiological pressure functions are concerned.

Vehicles flying in these altitudes may technically be aircraft, but physiologically they are aerospace craft and their flights are of the space-equivalent type. With increasing altitude, with the cessation of light scattering and sound propagation, and with the gradual appearance of the whole electromagnetic radiation spectrum of the Sun, of particle rays in their primary form, and of meteorites, the environment, although still atmospheric, becomes more and more space-equivalent until with the disappearance of air resistance at about 200 km, the environmental picture of space is practically complete.

The medical evaluation of this true space beyond the "mechanical border" of atmosphere, where the Kepler regime begins, has to concentrate upon the regional and temporal variations as they are found especially in the radiation climate, because understanding them is decisive for choosing the safest routes and times for the various space operations. They even set definite limitations to manned spaceflight. We can now say that the arena for manned satellite flight will have to be confined to the region from 200 to 800 km, the inner border of the inner zone of Van Allen's radiation belt.

Only low orbits, as we might call orbits below the radiation belt, are practical for manned flight. Medium orbits, which cover the whole great radiation belt from 800 to 80,000 km, are too hazardous, and therefore prohibitive, and the high orbits beyond this altitude probably are not very practical or useful. It is too early to make definite statements as to what degree of shielding will be required for protection from the basic particle ray flux, especially from those particles trapped and concentrated in Earth's magnetic field. The same is true concerning the jet streams of solar plasma ejected from the Sun, especially during solar eruptions. I would like, therefore, to confine myself to the statement that the radiation dosage inside the cabin has to be kept below the minimum permissible level which is determined by a significant health or performance decrement.

A medical evaluation of the topographical distribution of the high-energy particles and their temporal fluctuations is an important but difficult task of an ecological spatiography. The same task is somewhat simpler with regard to the solar electromagnetic radiation, as its intensity distribution follows a fixed pattern; namely, the inverse square of the distance law. Because of this, we find tremendous variations within the solar system. High intensities may be harmful for manned spaceflight on the one hand, and may be put to use on the other. Table 1 shows the total solar irradiance, expressed in cal/(cm^2·min), and solar illuminance, expressed in lumen/m^2 (lux), for the mean distances of the various planets from Mercury to Pluto.

The intensity of the total radiation from the Sun, including heat radiation (essentially infrared) at the top of Earth's atmosphere, is roughly 2 cal/(cm^2·min). This value is known as the terrestrial solar constant. Using the values at Earth's distance as a baseline, we find that the intensity factor for total irradiance and illuminance nearly doubles at the orbital distance of Venus, and at the mean orbital distance of Mercury it is more than 6 times as high. At the distance of Mars the intensity decreases to less than one-half, at Jupiter's distance to one twenty-seventh, and in the remote region of Pluto to one sixteen-hundredth of the terrestrial value.

In the first place, we think of heat radiation in connection with the temperature control of the spacecabin. Heat transfer in space, of course, is achieved only by radiation.

TABLE 1. SOLAR IRRADIANCE AT THE MEAN DISTANCE OF PLANETS

Planet	Mean solar distance (10^6 km)	Intensity factor	Total irradiance cal/(cm^2.min)	Illuminance (lux)
Mercury	57.9	6.67	13.3	935,000
Venus	108.2	1.91	3.8	267,000
Earth	149.6	1.00	2.0	140,000
Mars	227.9	0.43	0.86	60,300
Jupiter	778.3	0.0369	0.074	5,170
Saturn	1428	0.0110	0.0022	1,530
Uranus	2872	0.0027	0.0054	380
Neptune	4493	0.00111	0.0022	155
Pluto	5910	0.00064	0.0013	90

We immediately recognize that there is a zone in our solar system in which heat radiation is not too different from that at the Earth's distance, and, therefore, not too hostile to space operations. On both sides of this zone, however, it turns to extremes. We can therefore differentiate between an euthermal zone (from Venus to somewhere beyond Mars) adjoined by a hyperthermal and a hypothermal region.

The space-medical conclusions from these extreme variations in solar thermal irradiance are obvious. It makes a great difference in cabin temperature control whether a space operation is planned into the furnace-like radiation conditions within the orbit of Venus, or into the sparsely irradiated environment beyond Mars or Jupiter. The temperatures measured within the shell of the Explorer and Vanguard satellites were well within the physiologically tolerable range, around 25°C. But a spaceship penetrating the intra-Mercurian space would inevitably run into a kind of solar heat barrier, as symbolized by the legendary flight of Icarus; and a trip into the region of the outer planets requires temperature control measures very different from those in the realm of the inner planets.

We find a similar zonal pattern in solar light irradiation, or solar illuminance. Again, we might speak of a euphotic belt zone, 100 million km on both sides of the Earth's orbit, adjoined by a hyperphotic and hypophotic zone.

This zonal pattern in the photic environment of space has significance in two respects: with regard to vision and to the utilization of light in photosynthetic recycling of metabolic material in the closed ecological system of the spacecabin.

With regard to the latter problem, solar illuminance drops, as the distance from the Sun increases, below the effective minimum required for photosynthesis; this limit may be reached somewhere in the region of the belt of the asteroids.

Concerning vision, I would like to mention only that looking into the Sun can produce retinal burns in a relatively short time--less than 10 seconds--and that the retina-burning power of the Sun might extend as far as Saturn. These conditions necessitate protective mesures for the eye in the form of automatically functioning light-absorbing glasses.

Concerning ultraviolet and X-rays in space, not enough physical data are available at present for a biophysical evaluation.

The best indicators for the regional differences in total solar radiation are the comets which--hibernating as icy mountains of dirt, frozen water, ammonia, and methane (F. Whipple)--come to life by displaying gigantic tails as soon as they come closer than three astronomical units to the Sun.

Thus, we find only in the region from Venus to somewhere beyond Mars a zone in which solar radiation is not too different from that on Earth and which is more suitable for space operations without excessive protection requirements.

Finally, collisions with meteorites and micrometeorites seem to be not too great a problem, as indicated by recordings in satellites; but there are also meteor streams moving in former orbits of disintegrated comets and probably greater concentrations of meteoric material in the belt of the asteroids. For extended space operations, meteor bumpers (Fr. Whipple) are indicated, which might be combined with shielding devices against radiations.

All of this demonstrates clearly that, for the purpose of manned spaceflight, we need a geographic approach in the medical evaluation of the environment of space--in other words, an ecological space map, or a spatiography. Spatiography, of course, refers only to the space between the celestial bodies. The description of the conditions found on these celestial bodies is called planetography. Both spatiography and planetography are parts of an all-embracing cosmography of our solar system.

A few comments on the most probable target celestial bodies: On the Moon, space with practically all its properties immediately touches the ground. On the Moon's surface there is ecologically a true space environment.

The Martian atmosphere shows at ground level the same pressure conditions as our atmosphere at about 16 km. It must, therefore, be characterized as a critical atmosphere for man. It becomes supercritical, as manifested in the occurrence of ebullism, at an altitude of 3.5 km, which corresponds to 20 km in our atmosphere. The atmospheric environment on Mars, therefore, is space-equivalent very close to its surface.

To sustain human life on Mars and, of course, on the Moon, requires a sealed compartment of the same type as in space itself.

The development of effective intracabin life-supporting systems is a condition sine qua non for the realization of spaceflight just the same as the provision of protective capabilities of the cabin's shell against the surrounding vacuum, radiations, and meteorites which I have already mentioned.

Because of lack of time I cannot discuss some general vital ecological factors in the cabin's environment, such as temperature, pressure and composition of air, control of humidity and of odor; instead, I would like to make only a few remarks about the respiratory and nutritional metabolic side of the vital necessities in spaceflight and their procurement.

To supply the respiratory requirements, the following methods are available or conceivable. First, replacement of the consumed oxygen from storage tanks and elimination of carbon dioxide by chemical absorbents and storage of the absorbers. This storage method is the measure of regeneration of the cabin's air for short-time space operations, up to perhaps 2 months. Beyond this duration, the logistic difficulties become prohibitive when we consider that for such a period an oxygen reserve of 50 kg per man would be required, and more than this amount for chemicals for the absorption of carbon dioxide and water vapor.

The solution of this problem is regeneration of air and of absorbents by physicochemical means. This method might be logistically acceptable for a duration of 1 year. Beyond this time, reconstitution of all vital necessities (air, water, and food) is necessary if we wish to stay within the payload capabilities of rockets. The method of choice, then, is biological recycling as we see it in free nature in the biotic relationship between animals and plants: in the process of photosynthesis, found in all chlorophyll-bearing vegetation. In this process carbon dioxide is consumed and oxygen is produced--the reverse of respiration. Algae in a nutrient solution are used as photosynthetic gas exchangers in laboratory experiments. With 1.5 pounds of algae we can meet the respiratory requirements of one man. But in photosynthesis, carbohydrates are also produced, thus providing material for nutrition. To this end photosynthetic recycling must include all body wastes in addition to carbon dioxide and water. With such total recycling we can achieve a true closed ecological system. Since photosynthesis requires light, and most probably solar light will be utilized, it is a Sun-dependent closed ecological system. As already mentioned, however, solar illuminance drops below the effective minimum required for photosynthesis somewhere near the belt of the asteroids. The production of its own light by a nuclear powerplant, then, will make the vehicle a Sun-independent or an autarkic closed ecological system. Such will be the various phases in the development and utilization of the intracabin life-supporting systems.

The groundwork in developing these systems has to be done in the laboratory. A basic research tool for this purpose is the spacecabin simulator--a completely closed chamber in which the changes of the intracabin climate produced by the presence of occupants are recorded and controlled. The Aerospace Medical Center, Brocks Air Force Base, Texas, has a new 2-man cabin simulator. Photosynthetic gas exchangers are being developed using algae of various types such as chorella, anacystis, etc. They are connected with animal-containing chambers, thus forming a closed ecological system. The spacecabin simulators also permit studying the occupant's reactions to confinement and isolation, and observations about day-night cycling. Experiments in a 2-man spacecabin simulator over a period of 2 weeks are now a matter of routine and have given us indispensable information for preparing men for actual spaceflight. These spacecabin simulators are, of course, also useful tools in the selection and training program for prospective astronauts.

We cannot, of course, simulate all spaceflight conditions in the laboratory; e.g., dynamic weightlessness. This condition has to be produced in actual flight maneuvers. The effect of dynamic weightlessness upon man--for a period up to 1 minute--is well known. To what degree it is justified to make extrapolations concerning human physiological effects from animal experiments in suborbital flight and from Laika's orbital flight, lasting for longer periods of time, is uncertain. It is to be hoped that longer lasting manned flight will soon give vitally needed information in this respect.

Valuable data have been obtained by a prolonged submersion in water, in which certain features of zero-gravity effects can be produced. Dr. Graveline stayed for a full week submerged in water with only 1 hour/day intermission. One outstanding symptom of this experiment was that with every day during this hour outside the water, he felt weaker and was eager to get back into the tank. The hypodynamic condition produced his physical weakness, but he stayed mentally alert. A hypodynamic effect, of course, can be expected in true weightlessness; adequate and even enjoyable methods for exercise to prevent this must be applied.

Another conspicuous symptom was that the subject needed only 1.5 hours of sleep per day. This opens new aspects concerning cycling of sleep, rest, and activity of the astronaut and sheds some new light upon the validity of the various sleep theories in general.

Another subject matter, not so much discussed, is that of blood pressure during weightlessness. Dr. L. E. Lamb recently published some interesting data on the blood pressure at heart level, at the level of the base of the skull, and in the eye, considering the g spectrum from zero g to 5 g. With decreasing gravity we must expect a temporary increase of blood pressure in the upper part of the body. With decrease and absence of hydrostatic pressure, the blood pressure is more and more evenly distributed over the whole circulatory system--similarly as observed on Earth only while in the horizontal position. What physiological effect this blood pressure shift might have, after days or weeks, is a matter of space-medical interest. But in the background of all zero-gravity studies is still the question of its general tolerability over longer periods of time. If this should not be the case, then we must provide for artificial gravitation by rotation in order to achieve some level of gravitational normalization of life in the cabin. And the most logical g value would be the gravity of the target celestial body; i.e., 17% of 1 g for a trip to the Moon and 37% of 1 g for a Martian journey.

So far I have discussed some basic space-medical problems and studies centered around the space environment and experimentation in the laboratory. The question arises: Can space medicine give effective support to the realization of all the many space projects proposed by technology? Where do we stand today in actual medical space activities, and what are the prospects in this respect for the future?

Concerning animal experiments, there has been considerable progress during the past 9 years, as evidenced by a great number of suborbital flights with mice, monkeys, dogs, and rabbits in the United States and Russia. These ballistic dips into space have been exceeded by the Russian dog Laika's orbital flight in October 1957.

Concerning man's advance on our vertical frontier, the record balloon flight of Lt Col David G. Simons up to 30 km in 1957 and the flight of Capt I. Kincheloe in a rocket-powered plane up to 38 km in 1956 were, to a high degree, flights of the space-equivalent type (within the atmosphere above 20 km). More extended suborbital flights are in preparation with rocket-powered winged vehicles, and the first phase of true spaceflight in a satellite seems to be not too far off.

Such is the state of affairs in the penetration of space with biological specimens--man and animals.

What can we expect in the future? The plans and projects offered in the astronautical literature are numerous and sometimes vague, and some go far beyond the solar system. The potentialities in the space age seem to be limitless, and velocities appear to have become meaningless. Everything is taken almost for granted. From a medical point of view this is not so! Some of the projects are sound and are indeed a unique challenge for space technology and space medicine, but there are also definite limitations from the viewpoint of the physician.

After more than 10 years of theoretical and experimental studies, space medicine can make, and indeed is obliged to make, definite statements in this respect in the interest of the safety of the astronaut and to avoid devious projects in the space programs.

In the following we shall put the accent upon the limitations that reflect the medically acceptable possibilities. I have already mentioned certain limitations brought about by the enormous variations in the radiation environment of space and in the environment on the celestial bodies. At this point I would like to single out the time factor or the duration of extended space operations, which is related to velocity and which by itself can become a limiting factor.

The interplanetary and planetary space projects, based on present propulsion systems, involve considerable durations. These methods permit only minimum-energy trajectories to other celestial bodies. This fact finds its expression in the term "coasting," or "passive phase" of the trajectory. A flight to the Moon and return in this way is a matter of less than a week. This would probably not pose insurmountable medical problems. A flight to Mars based on a low-energy orbit, however, requires more than 8 months. The experiences gained in spacecabin simulators indicate that flights of such durations in a sealed compartment under the conditions of confinement and isolation might meet with difficulties. They arise, essentially, from the necessity to recycle the total environment and from the psychophysiological nature of the human creature. It seems to be necessary to develop more effective propulsion methods in order to shorten the duration of interplanetary missions. This, of course, would mean a change from a minimum-energy orbit to a minimum-time orbit, which would require either additional brief or even continuous slight accelerations. This formula for a medically acceptable duration should almost be regarded as a "physician's prescription" to astronautics. A compromise concerning the duration of interplanetary flight has to be achievable from the standpoint of space technology, and permissible from the viewpoint of medicine. The size of the cabin and the comfort that can be offered to the astronauts, of course, play an important role in this matter.

Continuous slight acceleration, if it can be maintained long enough, leads to very high velocities, ultimately approaching the speed of light. But not every velocity envisioned for interstellar flight is acceptable from a medical point of view because extreme speeds change the space environment for the vehicle and the crew. The collision energy of meteorites, dust particles, and the atoms of interstellar gas will become higher. Rushing through the omnidirectional flux of cosmic rays increases their energy level at impact upon the vehicle. The spaceship might run into a self-produced "disintegration barrier." This shows that velocity in higher fractions of the speed of light becomes a limiting factor by its effect upon the environment related to a space vehicle and its occupants. Time dilatation associated with near-light speed is often discussed as a phenomenon favorable to interstellar flight. Flights over interstellar distances are presently not conceivable, however, for the aforementioned biological as well as physical reasons, and the operational range will almost with certainty be confined for an indefinite period to the celestial bodies of our home solar system. But even this more modest goal, even if limited to the neighboring celestial bodies--Moon, Mars, and Venus--will be one of the greatest achievements in human history. In addition, it may open new horizons to the biological sciences. This leads us to the second part of this paper: astrobiology.

Biology is that field of science which studies life as it is known to us, in all its forms, functions, and phenomena, and its environmental and biotic interrelations. Astrobiology extends such thinking to other celestial bodies such as the planets and their moons. It is a fruitful combination of astronomy and biology.

Since, as yet, we do not know anything about creatures on other celestial bodies, the ecological aspect is presently the only one on which astrobiological studies can be based. The term "astrobiology" appeared for the first time as the title of a book written in 1953 by G. Tikhov, in Russia, and in the same year appeared in the text of a book by H. Strughold; in 1957, it was the title of a book of F. Pereira, Brazil. Actually this line of thinking goes back almost a century, initiated by a report written by G. Schiaparelli in 1887 about "canali" on Mars. Since then several books have appeared about life on other planets.

The rapid development of rocketry in the past 10 years has given a tremendous impetus to the problem of life on other worlds, in addition to the specific questions as to what kind of environment an astronaut would find on the Moon and the planets with regard to his own survival, which we have already touched upon.

Astrobiological considerations can be based on: (a) the assumption of the kind of life known to us, based on carbon as the basic structural atom and on oxygen as the basic energy-liberating atom, or (b) the assumption of other forms and processes of life, unknown to us and based on other elements; for instance, silicon as the fundamental structural atom. This extracarbonic biology is beyond the scope of this discussion.

The studies in astrobiology include theoretical considerations, visual observations, spectrographic analysis, and experimentation.

First, in theoretical studies, the application of certain basic ecological principles has brought some order into astrobiological thinking. By applying the well-known ecological cardinal points such as the minimum, optimum, and maximum points, or the principle of limiting factors with regard to certain vitally important environmental components such as temperature, light, and presence of water, carbon dioxide, and oxygen, we arrive at a zonation of the ecological picture of our planetary system: an analogy to the climatic zonation of Earth. Such an attempt, of course, is valid only for carbon-based biology of the general type known to us.

In the first place, it is solar radiation which has a decisive effect upon the ecological qualities of the planets. More in detail, beginning with temperature, we have already defined a euthermal belt adjoined by a hyperthermal and hypothermal region in interplanetary space from the point of view of space operations. This consideration applies, of course, also to the conditions on the planets. Venus lies in the hot and Mars in the cold border zone, and Earth is in the golden middle of this euthermal, or biotemperature, belt. Jupiter, Saturn, Uranus, Neptune, and Pluto move in the remote hypothermal region and are correspondingly, so to speak, permafrost planets.

This thermal aspect immediately leads to the question of the presence of water on the planets in its biologically usable (liquid) form. Harlow Shapley speaks of a liquid water belt in the planetary system, which includes Earth and, with some reservations, Mars and Venus.

Similarly as in the case of heat radiation, we subdivide space into photic zones. The regions from Venus Sunwards can be regarded as highly hyperphotic and those beyond Mars as hypophotic. But the zones between them may be considered as euphotic, or biophotic.

The astrobiological significance of the ultraviolet section of solar radiation is evidenced by its effect upon the chemistry of the planetary atmospheres. To understand this we have to consider the historic development of the planetary atmospheres and the evolution of their chemoecological qualities, which leads us into the field of paleo-astrobiology. According to H. Urey, G. Kuiper, and others, at proto-planetary times (some 2 billion years ago), all planetary atmospheres had about the same chemical composition: hydrogen and hydrogen compounds like ammonia, methane, and water. In the course of millions of years under the photochemical effect of ultraviolet of solar radiation, these reducing protoatmospheres have been transformed into atmospheres containing free oxygen and/or oxygen compounds, but only in the range from Venus to Mars. We know that with regard to the Earth the appearance of green plants (algae) some 1.5 billion years ago has, through photosynthesis, played an even greater role in the oxidation of its atmosphere. Be that as it may, the aforementioned planets form an oxygen belt in the planetary system, with the Earth as the exemplary oxygen planet; whereas Mercury, Venus, and Mars apparently lost this bioelement due to high temperature or low gravity.

The outer planets, due to their orbiting beyond the effective reach of solar ultraviolet and their high gravities, have preserved their protoatmospheric chemical composition up to the present. They form a hydrogen belt of the primordial brand in the planetary system. They are still protoatmospheres.

This general ecological consideration leads to the assumption of specific life-favoring ecological belts in the planetary system, such as a biotemperature belt, liquid water belt, biophotic belt, and oxygen belt.

To cover all of these ecological factors we can use for this life-favoring zone the more general term "ecosphere" in the planetary system, or helioecosphere. This ecological belt, or the region of the "golden orbits," is a relatively narrow zone and represents not more than 4% of the whole range from the Sun to Pluto. In this belt, total solar irradiance ranges from roughly 4 to 0.5 cal/cm^2·min) and solar illuminance from 300,000 to 40,000 lux (lumens/m^2). For comparison, the corresponding values on the Earth's surface reach, maximally, 1.4 cal/(cm^2·min) and 100,000 lux, respectively. The concept of the ecosphere, also referred to as habitable zone, has been applied to other stars recently (J. Gadomski, and others).

Individual Planets. From all of these general ecological considerations it seems to follow that, besides Earth, only Mars and perhaps Venus may qualify as bioplanets.

On the outer planets, microorganisms such as hydrogen bacteria, methane bacteria, etc., are conceivably just the same as in the terrestrial protoatmosphere if the temperature on the surface is in physiological limits.

Of the ecospheric planets, Venus, constantly and completely covered with dense clouds probably consisting of carbon dioxide crystals, is wrapped in mystery concerning its surface features. The thermal environment on this planet might be on the hot side due both to its nearness to the Sun and to a "greenhouse" effect in its carbon-dioxide-enriched atmosphere.

The Martian atmosphere is rather transparent and permits observation of the planet's surface. Because of this, Mars is the favored planet for astrobiological discussion and has been so since Schiaparelli's description of canali and the observation of dark-green areas that show seasonal color changes of the kind we observe in terrestrial plants. They have recently again become the subject of intensified studies with the improvement of spectrographic techniques and the possibility of transatmospheric observations from balloons.

There are three theories concerning these dark-green areas on Mars:

(1) the organic or vegetation theory,

(2) The inorganic theory explaining them as the result of either volcanic eruptions (P. McLaughlin) or of color changes of some hygroscopic inorganic material caused by variations of the soil's humidity (S. A. Arrhenius),

(3) the physiological optical theory which explains the green color as a contrast phenomenon against the yellow-red surroundings.

In the following I shall confine myself to those theories which involve biological or physiological aspects.

Concerning the vegetation theory, we must consider the following climatic data: oxygen is present on Mars only in traces, the carbon dioxide pressure is considerably higher than on Earth, and nitrogen is in abundance; water, however, is very scarce. The light intensity is about 40% of that on Earth, high enough for photosynthesis of the kind we know. The amplitude of the day-night temperature variations in the equatorial regions can exceed 70°C. During the day the temperature can reach 25°C but drops during the night to -45°C and lower.

In general, then, the physical conditions are, in terms of terrestrial botany, extremely severe with the exception of sufficient carbon dioxide and light and suitable temperatures during the day.

Such conditions could, according to terrestrial standards, support only very hardy and cold-resistant organisms.

But we must consider not only the climate as a whole but also the so-called microclimate near, on, and below the ground, influenced by surface and subsurface features--snow coverings, hollows, caves, etc.--which usually moderate the extremes of the macroclimate.

And then we must not only look upon the physical ecological side of the problem but also upon its physiological side; that is, the enormous capacity of life to adapt itself to abnormal climatic conditions. With regard to the specific environment on Mars, we should consider the possibility of adaptive phenomena such as storing of photosynthetically produced oxygen in intercellular spaces, as we find them especially in the leaves of water plants; storing of carbon dioxide in tissue fluids; storing of water as in our desert plants; a stronger absorbing power of the plant surfaces for infrared, for temperature control, as it has been found in our subarctic plants. Protection against frost could be imagined if the Martian plants were able to produce some kind of antifreeze such as glycerol as a metabolic by-product. When searching for clues in the botanical literature, I found that some of our terrestrial lichens de facto contain erythrol, which belongs to the same class of chemicals as glycerol.

These are some theoretical considerations. What are the results of observational and experimental studies?

Dr. William M. Sinton, Smithsonian Observatory, found recently strong absorption bands near 3.4 μm, the wavelength of the carbon hydrogen bond. This indicates the presence of organic molecules. He emphasizes that this organic material would easily be covered by dust from storms unless it possesses some regenerative power. A strong regenerative power was first postulated by E. G. Oepic.

Audouin Dollfus (Mendon Observatory, Paris) with L. Focas (Athens, Greece) made polarimetric and photometric observations of Mars and, for comparison, on mixtures of dirt and plant material. His results, too, favor the vegetation theory.

In Russia the outstanding Mars researcher was the astronomer G. Tikhov at the Alma Ata Observatory. He studied the optical properties (reflection and absorption) of terrestrial plants and compared them with those of the dark-green areas on Mars. He, as well as G. Kuiper, could not find the main absorption band of chlorophyll in the spectrogram of the dark-green areas. But he found strong absorption in the infrared. He observed the same on plants growing under severe conditions as on the Pamir Plateau in South Central Asia and in the subarctic. He advanced the opinion that the colder the climate, the less is the reflecting power of plants in the main heat-carrying rays from infrared to red and yellow. Optically, this means that their color is shifted to the bluish side. Ecologically, it means that they absorb more heat. Since the dark areas on Mars show a strong bluish-green tint, Tikhov thought that the plants on Mars have developed just these optical properties for adaptation to the severe Martian climate. All of these properties, manifested in the color of plants, are, essentially, adaptations to the general level of the environmental temperature. On Mars, therefore, where the climate is vigorous, the plants are in shades of blue; on Earth, where the climate is intermediate, the plants are green; and on Venus, where the climate is hot, plants should have orange colors--according to Tikhov. He first published his findings and conclusions in a book entitled "Astrobotany" in 1947, and "Astrobiology" in 1953. He also founded a Department of Astrobiology with an astrobotanical garden at the Alma Ata Observatory. Another Russian scientist, Olga W. Troizkaya, is not so optimistic. She gives only anaerobic, very cold-resistant microorganisms a chance in the Martian climate.

Most of the astrobiological researchers are in favor of the Martian vegetation theory. Nevertheless, the problem of the green areas on Mars is far from being solved. Especially is it difficult to explain their rapid expansion in the Martian spring. Following the melting of the icecaps, they progress towards the equator with a speed of 7 to 15 km per day. No such growth rate is known to us in the terrestrial plant kingdom, as has been emphasized by Dr. Frank Salisbury. Perhaps one could explain it by a sleeping, drooped position of the leaves during the winter--a kind of hibernation. Then it could be imagined that in spring they expand in a horizontal position, fully exposed to sunlight and to the eye of the astronomer.

But the human eye as such also requires attention in the astrobiological evaluation of the dark-green areas. Are the green colorations on Mars real or are they a contrast phenomenon? First of all, observation of the green areas on Mars requires *normal color* vision of the observer, as has been emphasized by Dr. Ingeborg Schmidt, Indiana University. The same author made experimental studies with gray patterns of different forms and sizes seen on a yellow-red background and came to the conclusion that some of the green colorations on Mars are probably contrast phenomena, especially if the areas are small. This conforms with earlier observations of G. Kuiper, who, with great magnification, found only traces of moss-green colorations when observing peripherally with the eye. All centrally viewed areas appeared dark gray. But green or not green, it does not exclude the possibility of vegetation on Mars.

All this shows that the question of life on Mars is presently in a lively flux of theoretical, observational, and experimental studies, but it might be that the final answer will not be available until the first astronaut sets his foot on this "red," or "red and green," or "red and apparently green," planet, and telemeters his findings down, or up, to his home, or not-any-longer-home planet Earth, to the delight or disappointment of the followers of the various Martian theories.

A new experimental line of astrobiological studies is that of examining terrestrial microorganisms under simulated Martian conditions in a Mars chamber, or Marsarium. These studies indicate that certain kinds of soil bacteria perish; others, however, not only survive but increase in numbers during exposure to an environment in which most of the Martian atmospheric conditions (air pressure, composition, and temperature) are reproduced. Such experiments, which should be extended in Venus chambers and Jupiter chambers, are not only of astrobiological interest but also of general biological interest insofar as in this way the struggle for existence of life, as conceived by Charles Darwin, is shifted from a terrestrial to a cosmic level. They are also of significance with regard to contamination of other celestial bodies by terrestrial microorganisms, and vice versa. This subject matter may become an important subfield of astrobiology.

The sterilization of rockets and space vehicles is of very great astrobiological significance. It has been reported that the Russian rocket that hit the Moon had been sterilized. One of the very effective chemicals is ethylene oxide gas. But it must be mentioned that blowing this gas into the interior of the rocket is not enough. Sterilization of space vehicles has to begin in the phase of manufacturing electronic equipment. All of this refers to unmanned space, lunar, and planetary probes. With manned space vehicles it is a different story. In this case, contamination of the environment of other celestial bodies with terrestrial microorganisms, and vice versa if there is indigenous life on the target celestial bodies, seems to be unavoidable. Exoterrestrial life contaminating Earth via space vehicles might be absorbed in the melting pot of the endoterrestrial life. On the other hand, terrestrial microorganisms might find a suitable environment on other celestial bodies. When brought to virgin atmospheres such as those of Jupiter, they might start a stormy chemical transformation of its atmosphere if temperature and light conditions are adequate. We must remember that the appearance of algae on our planet some 1.5 billion years ago has played a greater role in the oxygenation of our primordial atmosphere than the oxygen production by photochemical reactions.

In the biological literature, we find the various historic periods of life on Earth listed as Archeozoicum, Paleozoicum, Mesozoicum, and Neozoicum. But if by space vehicles, forms of exolife would contaminate the Earth and be integrated in the complexity of terrestrial endolife, we will have entered a new era which we might call Cosmozoicum.

Astrobiology, of course, is also interested in the question of the origin of life. In this respect there are two theories. First, the panspermia theory, suggested by Swante Arrhenius, 1910, according to which, microorganisms are distributed through space under the effect of light pressure or by means of meteorites as carriers.

Another theory suggests that life originated independently on individual planets. Concerning Earth, it has been theorized that in its protoatmosphere containing hydrogen, ammonia, methane, and water vapor, some 2 billion years ago organic compounds such as amino acids were produced by ultraviolet of solar radiation, cosmic rays, or lightning, and settled down in the oceans and turned them into a kind of organic "nutritional" soup. This prebiotic material is considered to be a precondition and prestage for the origin of life. That such photochemical or electrochemical reactions occur could be verified 6 years ago by means of electrical discharge in a chamber containing the gas composition of the primordial atmosphere (S. Miller).

After the discovery of the Van Allen belt, it now suggests itself that the particle rays trapped in the geomagnetic field may have played a role in this respect. The horns of the outer radiation belt, which dip considerably into the atmosphere in the subarctic latitudes, manifested in the polar lights and increased temperatures, may have been especially effective locations, particularly after solar flares, for the production of prebiotic material. Such an assumption would also be of interest concerning the possibility and origin of life on other planets. I think the inclusion of the geomagnetically produced radiation belt, in addition to solar ultraviolet radiation, into the problem of the origin of life at protoatmospheric times offers a promising platform to the physicist and biologist for theorizing and experimentation.

These are, in brief, my remarks in reviewing space medicine and astrobiology. We, from the life sciences sector of astronautics or bioastronautics, are proud of the opportunity to work together with space technology on the realization of man's penetration of space. In these efforts there are even broader aspects involved. Terrestrial medicine, in general, will benefit from the study of the behavior of the human body under extraterrestrial conditions, and the extension of our biological thinking into a cosmic spectrum will offer unthought-of vistas for the searching human mind for generations to come.

THE PHOTIC ENVIRONMENT IN SPACE AND ON THE NEIGHBORING CELESTIAL BODIES: BIOLOGICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

Light is a very important ecological factor for most living creatures. In this connection two types of biological substances that are specifically sensitive to light play a vital role:

(1) Pigments in the eye's retina, such as rhodopsin, that react, in the case of man, to the 3800-7800 Å range in the electromagnetic radiation spectrum--which is the biochemical substrate for vision.

(2) Chlorophyll found in green plants, which is specifically attuned to about 6600 Å in the red section and 4400 Å in the blue and is the enzymatic agent in the photosynthetic production of organic matter and oxygen.

Therefore, vision and photosynthesis are the two sides in the biological aspect of the photic environment of space and on the neighboring celestial bodies, the Moon and Mars, which I have the privilege of discussing at this Symposium on Submarine Medicine and Space Medicine. With regard to the photic environments that submarines and space vehicles encounter, there are in certain respects extreme contrasts; but conforming with the French proverb "les extremes se touchent," there are also some similarities. We shall therefore make some photobiological comparisons between the sea and space, and we must include, of course, the atmosphere that modifies the original solar radiant flux to that photoclimate to which man is accustomed.

Light conditions in any environment are determined by the kind and distance of the light sources to which the environment is exposed, and by the optical properties of the environmental medium. In the environmental media that we discuss, the primary and predominant light source is the Sun. Its luminance** and illuminance** are the factors of special concern to us. The optical environmental properties that we must consider are reflection, scattering, and absorption of light. They influence the illumination from the Sun and determine the luminance of the sky and of the surrounding nonself-luminous celestial bodies.

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**See Glossary

In the following photoenvironmental analysis we shall consider the visual aspect first and, for a better understanding of the light conditions in space, begin with those found in the sea and on the Earth's surface.

Visual Aspect

The Hydrosphere. In the deepest regions of the oceans there is permanent darkness. It is interesting to note that in this lightless abyss numerous fish are found, some with light-producing (bioluminescent) organs and with eyes, and some with vestigial nonfunctioning eyes. Orientation and motion of these blind deep-sea fish are controlled by means of mechanoreceptors only. This is the biosphere without light, a world of eternal night.

This so-called aphotic zone of the seas ends at about 500-600 m below sea level, insofar as here the first slight traces of light become perceptible by the human eye, according to the observations made by W. Beebe (4) and Jacques Piccard (19) in their bathyspheres. These light traces are of bluish color and shift with decreasing depth to green and greenish yellow in the subsurface regions. In the upper 5 m of this photic zone, solar illuminance increases from 10,000 to some 50,000 lumens/m^2, or lux*. But even that close to the surface a diver perceives no clear evidence of the disklike image of the Sun.

The Atmosphere. Emerging from the hydrosphere to the bottom of the atmosphere, we see--during a cloudless noon--the Sun, high in the sky, its rim blurred by an aureole which blends into a dome-shaped sky of bluish light. The aureole is caused by indirect sunlight reflected by ice crystals in the higher atmosphere, and the blue sky is indirect sunlight scattered by the air molecules and fine dust. As seen from sea level the photometric brightness, or luminance, of the blue sky, about 25° from zenith is about 1600 nit* (H. Haber, 8). Because of this veil of scattered light the stars remain invisible, and the Moon is barely discernible. The illuminance from the Sun is roughly 108,000 lux (10,000 footcandles), which is the average value at noon during sunshine at sea level at middle latitudes in summer (H. Haber, 8; E. O. Hulburt, 10).

Space. When man ascends in a space vehicle, he experiences a radical change in the photic environment. The sky gradually becomes darker and the Sun brighter because of the rarification of the air and the resulting disappearance of light-scattering. This has been observed in high-altitude balloon flight by Jean Piccard (18), A. W. Stevens and O. A. Anderson (1), D. G. Simons (23), and M. D. Ross and and M. L. Lewis (22). At 30 km (18 mi) the luminance of the sky

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*See Glossary

decreases to 30 nit, and at 160 km (100 mi) it is only about $3x10^{-5}$ nit (R. Tousey and E. O. Hulburt, 28). Against this low field brightness the stars are visible all the time. Because of the absence of a reflecting and scattering medium, the Sun now shines without an aureole, as a luminous disk on a dark background.

The Sun's corona scatters some of the light emitted from the photosphere, amounting, totally, to one-half of the brightness of the full moon (Waldmeier, 32). But against the brilliance of the solar disk this will not be perceptible to the human eye. The situation is different, of course, during a total solar eclipse as seen either from Earth's surface or from space. The color of the Sun (and of the stars) should be more whitish, because no blue rays are scattered out by an atmospheric medium. Solar illuminance increases from its maximal sea-level value of about 108,000 lux to about 140,000 lux at the top of the atmosphere (13,600 footcandles* according to H. Haber, 8; 12,700 fc, F. S. Johnson, 11; 14,000 fc at 30 km, R. B. Toolin and V. J. Stakutis, 27). This extraatmospheric value is called the solar illuminance constant.

Such are the basic differences between the hydrospheric, atmospheric, and extraatmospheric photic environment in nearby space during the day: darkness in the deep sea, and in its photic zone, diffuse indirect light; a bright blue sky of indirect light centered around the direct light of a bright Sun in the atmosphere; and a permanently dark sky with the direct light of a still brighter Sun in space at the Earth's orbital distance.

The darkness of space, however, is not the same as that in a moonless, clear sky on Earth at midnight, where the luminance of the dark sky between visible stars (the background luminance) is greater. In the first place this is caused by night airglow in the upper atmosphere--a faint, diffuse light emitted by atomic oxygen, nitrogen, and sodium brought into excited states by solar ultraviolet rays (D. Barbier, 2).

The northern and southern regions of Earth, of course, often show the polar lights, the aurora borealis and aurora australis. These fascinating light phenomena are produced by the bombardment of the air molecules and atoms by protons and electrons ejected from the Sun, especially during solar flares, and channeled by the geomagnetic field toward the polar regions.

If we omit these regional polar lights, then in the order of decreasing relative intensities, the total night light of a terrestrial clear, moonless sky, comprises airglow, starlight, zodiacal light--sunlight reflected or scattered from micrometeorites and dust particles (H. C. Van de Hulst, 31; D. E. Blackwell, 5), and galactic light (nebulae); all direct and scattered by Earth's atmosphere (S. K. Mitra, 15). The

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*See Glossary

scattered component gives the background luminance a hardly noticeable bluish shade. The total luminance is in the order of 10^{-4} nit (11). The dominant light source, airglow, is absent from the sky in space.

The total light encountered in the dark sky of space includes, therefore, only direct starlight, zodiacal light, and galactic light. The dominant light source is the stars. The total luminance of the dark space sky is in the order of 10^{-5} nit, by a factor of 10 lower than that of the terrestrial sky at night.

In the night sky, as seen from Earth, the stars are embedded in the mild luminance of the airglow, which mollifies the contrast between them and the surrounding darkness. With airglow absent in space, zodiacal light remains the main background luminance, at least up to the distance of Jupiter (J. M. Levitt, 12). The stars in space should appear brighter by contrast with the darker background. Actually they are brighter by about 30%; this is the amount of the attenuation of light while travelling vertically through the atmosphere. For the same reason more stars should be visible from above the atmosphere than from the Earth's surface; and, of course, they would not twinkle because no atmospheric turbulence interferes. This was observed by D. G. Simons (23) during his balloon flight up to 30 km in 1957.

So much about the basic light conditions an astronaut orbiting around Earth would experience in altitudes from 200 to 800 km. This is the region to which manned satellite flight will be confined because of the Van Allen radiation belt, beginning at 800 km.

When the Moon is in sight from an orbiting space vehicle, the Sun-illuminated portion would be brighter by about 30% than when seen from Earth, because the atmosphere no longer interferes. Brighter, also, should be the Moon's portion not directly illuminated by the Sun. This luminosity is "earthlight on the Moon," which is actually indirect sunlight reflected from Earth.

With this we arrive at Earth itself as a source of light. Of the solar light falling upon our planet, 36% is reflected or scattered back into space. Earth appears as an illuminated celestial body with an albedo value about 5 times as high as that of the Moon (0.07). Numerous photographs of Earth have already been made from rockets at considerable altitudes (C. T. Holliday, 9; J. G. Vaeth, 29). The color of the sunlight reflected or scattered back from Earth's atmosphere is bluish-white--a conclusion made from spectrographic studies of the "earthlight" on the Moon. A certain area of Earth would also show to the orbiting astronaut the moonlight on Earth, just as we see from Earth the earthlight on the Moon's dark areas. And, I should like to add that for the first time a bird's-eye view of the aurorae polares will be possible from a polar satellite. It might be interesting to learn whether or not astronauts will be able to perceive the so-called Gegenschein, or counterglow--a faint luminoscity far above Earth's atmosphere, opposite the Sun, the cause of which is still a matter of dispute. Some astronomers think that it is light scattered by a miniature cometary tail of atmospheric material which the Earth might possess.

Then there are the shadow regions in space produced by the solid planetary bodies. The cone of Earth's shadow extends to 1,385,000 km (860,000 mi); that of the Moon, to 375,000 km (233,000 mi); and of Jupiter, to 90 million km (56 million mi). These shadow cones are not visible to the astronaut because of the absence in space of light-scattering gaseous matter. He will become aware of them only when he is moving through them, in which case the Sun is blocked out of the black sky. These shadow cones in space are, of course, also of interest with regard to the temperature control of the spacecabin.

This whole complex of physical-optical situations in the upper atmosphere and nearby space are of greatest and immediate interest from the standpoint of space medicine, or bioastronautics. They pose psychologic, physiologic, and medical problems.

As seen from an orbiting space vehicle, the appearance of Earth as a light source in the photic environment of nearby space leads to a strange situation, in that it is bright "below" (or more precisely, Earthward) and dark "above" (or better, deep-spaceward). This is the reverse of the situation on Earth's surface, which appears generally--except in winter--as dark green or brownish in color, with a bright dome of skylight above. This strange spatial distribution of light and darkness in nearby space affects the astronaut's orientation, especially since the eye is the only sense organ on which the astronaut can depend in spaceflight, which in this respect is weightless. Under this condition the graviresponsive mechanoreceptors, or gravireceptors, such as the otolith organ, the pressoreceptors of the skin, etc., cannot provide any information concerning his position and movement in space. This is in contrast to the life of deep-sea fish with nonfunctioning eyes, which depend entirely on their mechanoreceptors for orientation as previously mentioned.

The low field brightness of the sky, combined with an intensive illumination from the Sun, represents a strange optical situation found on Earth only under artificial conditions; for example, theatrical stage lighting. Everything that is exposed to sunlight--outside and inside the cabin--appears extremely bright; everything in the shadow is dark. Light and shadow dominate the scenery. This photoscotic condition poses interesting problems in the field of contrast vision and retinal adaptation, and requires special attention in human engineering of the spacecabin windows (P. A. Cibis, 6; H. W. Rose, 21).

The bright Sun in a black sky gives the impression that in space there is, so-to-speak, day and night at the same time. An astronaut needs a sequence of rest and sleep and activity, so this requires artificial day-night cycling. In this respect space medicine can learn from experiences in submarine medicine. This is an example of a similarity of life in a nautilus and in future "astronautilus."

Hazards resulting from observation of the light sources themselves must be considered. Beginning with the weaker one, the Sun-illuminated portion of Earth may produce, at the plane of the eye, an illuminance value of more than 20,000 lux at satellite distance below the Earth's radiation belt (H. J. Merrill, 14). This might easily cause a dazzling glare (as described by T. C. McDonald, 13), with regard to higher atmospheric altitudes), especially when the orbiting astronaut emerges out of the shadow of Earth.

Special medical attention must be given to possible hazards to the eye caused by looking into the Sun. Retinal damages, with which we have to reckon, are actually heat effects caused by visible and near-infrared rays focused by the lens upon a small area within the fovea retinae. Such damage occurs frequently on Earth when a solar eclipse is observed with an insufficiently smoked glass. The result may be a retinitis solaris, and in severe cases a thermal coagulation necrosis of the retinal tissue, or a retinal burn. I acquired such a retinal burn in Europe when I observed the total solar eclipse on 17 April 1912 with my right eye insufficiently protected. A photograph made more then 40 years later shows that such retinal lesions are usually irreparable. The subjective symptom is a small blind area, or scotoma, in the visual field, which is called eclipse blindness (scotoma helieclipticum).

The critical exposure time for eclipse blindness to develop is estimated to be 1 minute or less. Outside the atmosphere the danger of such retinal lesions associated with visual defects, which generally might be called helioscotoma, is, of course, greater for physical and physiological reasons.

From data available in the literature concerning similar effects produced on rabbits by atomic flashes, it can be estimated that, in space, an exposure time in the order of 10 seconds or less at the Earth's distance might be sufficient to cause retinal burn. Caution in this respect, therefore, is indicated, and protection of the eye by automatically functioning light-absorbing glasses or electronic devices must be considered. How far the zone of the retina-burning power of the Sun extends has recently been discussed by O. L. Ritter (20). It may reach as far as into the region of Saturn. Even beyond this planet, according to H. W. Rose, looking into the Sun might cause a dazzling glare. (For more literature concerning solar injuries of the eye, see reference 26.)

We have already touched upon the light conditions in deep space, and we shall include the whole solar space from Mercury to Pluto.

In this area the illumination from the Sun is the factor which interests us most because it is subjected to considerable variations with increasing planetary distances. This is in contrast to the brightness of the sky, which is dark everywhere in space and may become a shade darker in the extra-jovian space because of the disappearance of the zodiacal background light. As mentioned before, solar illuminance above Earth's atmosphere at the Earth's mean solar distance amounts to about 140,000 lux. According to the inverse square law, in the region of Venus this value increases to 268,000 lux, and at Mercury's distance to 938,000 lux; it decreases at the distance of Mars to 60,000 lux, at Jupiter's distance to 5,200 lux, and at the mean orbital distance of Pluto to 90 lux.

From a biological point of view these tremendous variations in solar illuminance suggest that the space of the solar system is subdivided into photic zones. We might not go too far in speaking of a euphotic belt, which is the zone favorable to space operations and may include some 100 million km in the Sunward direction, and several 100 million km in the opposite direction as seen from the Earth's orbital distance; this zone is surrounded by a hyperphotic and hypophotic zone.

The euphotic belt (we might also call it the biophotic belt) is an important component in the concept of a general life-favoring zone or ecosphere, in the planetary system (H. Strughold, 24). Other components are temperature and occurrence of water and oxygen on planets.

In this connection, it might be interesting to consider the apparent size of the Sun as seen at the distances of the various planets.

To an observer on Mercury, the diameter of the solar disk would appear more than twice as large as when seen from Earth. As seen from Mars, the Sun would have a considerably smaller apparent dimension, about two-thirds of that seen from Earth. At the distance of Jupiter, the Sun's diameter is one-fifth as large as seen from Earth; and at the distance of Pluto, the Sun would appear about 3 times larger than the evening star (Venus) appears to us on Earth (25).

The illuminance from the Sun at the mean distance of Pluto is still 90 lux; this is considerably above the threshold for color vision. Below 10 lux color discrimination becomes difficult. Solar illuminance decreases to this value at about 3 times the distance of Pluto, or about 18 billion km (or more than 10 billion miles), from the Sun. Here, then, begins the colorless world of interstellar space, as far as it is related to the Sun's illuminating power. And the Sun, itself, as seen with the eyes of an interstellar space traveler, gradually joins the conventional scale of stellar magnitudes.

Returning to our local universe--the solar system--we have discussed so far the light conditions found in space as an astronaut would encounter them during orbital flight or on a journey to target celestial bodies. What about the light condition on the celestial bodies themselves?

Celestial Bodies. On the Moon, without an appreciable atmosphere, solar illuminance is about the same as above Earth's atmosphere (140,000 lux); 93% of this is absorbed by the surface, as indicated by the low lunar albedo value (0.07). This means that to a visitor on the Moon the sunlit terrain would not appear brighter than the landscape appears to us on Earth. But because of the absence of a light-scattering atmosphere, the lunar sky is permanently dark despite the bright shining Sun. Light-scattering ceilings on a lunar base and light-scattering visors attached to the helmet of the astronaut, serving as a kind of blue-sky simulator, may be useful to weaken and diffuse the Sun's concentrated burning rays and to produce sky conditions to which we are accustomed under the dome of the terrestrial atmosphere.

This probably is not required on Mars. Its atmospheric pressure and density at ground level are somewhat equivalent to those found in the region around 15 km (9 mi) in our atmosphere. At the top of the Martian atmosphere solar illuminance is about 60,000 lux. The intensity of daylight at ground level is lower than on Earth, but is still in physiologically desirable ranges. The color of the Martian sky is probably whitish blue (G. Kuiper) due to scattering of light by the various hazy cloud layers.

The day-night cycle is practically the same as on Earth, with a 7-minute difference. In contrast, the lunar day-night cycle of 27 terrestrial days requires, of course, artificial cycling.

About the light conditions on Venus and most of the other planets, we can only speculate because of the dense cloud covers enveloping these celestial bodies. And Mercury, with its Sunward hemisphere exposed to an illuminance of about 750,000 lux and without an appreciable atmosphere, will pose special problems because a manned vehicle entering the Mercurian space would become a victim of solarization, in the sense of overexposure to solar radiation, unless especially protected.

I have devoted the greater part of this paper to the photic environment found in space and on the neighboring celestial bodies from the standpoint of vision because this is always and everywhere a vitally important factor in the astronauts' psychophysiological world of confinement and isolation.

PHOTOSYNTHETIC CONSIDERATIONS

Solar light in space can become an important factor in the complex of life-supporting systems in the spacecabin; namely, for regeneration of cabin air and recycling of body wastes by means of photosynthesis.

Physicochemical means for this purpose are inadequate for reasons of logistics in extended space operations beyond 1 year, and biological recycling is the method of choice. Considerable work is being done along this line in the development of a closed ecological system (J. Myers, 16; J. G. Gaume, 7; J. N. Phillips, 17; J. H. Bates, 3). The question arises how far in space can solar rays be utilized for photosynthetic recycling; in other words, where in the solar space does solar illuminance drop below the effective light-intensity minimum required for photosynthesis? If we base our estimation in this respect on data available in the botanical literature and allow for a considerable loss of light energy in the photosynthetic device, we might, with 10,000-20,000 lux solar illuminance outside the cabin, be not too far off. This value is found around the belt of the asteroids. But all this depends to a considerable degree on the perfection and efficiency of the photosynthetic machinery. The optimum in solar illuminance for photosynthetic recycling may well lie within the helioecosphere which we defined earlier. And the maximum as a limiting barrier may be in the intra-Venusian space.

Another question I would like to touch upon is this: Are the light conditions on the planets in the adequate range to allow the terrestrial kind of photosynthesis? This is an interesting astrobiological question. We can make, in this respect, suggestions only with regard to Mars, which has an "open" atmosphere. At the orbital distance of this planet, solar illuminance amounts to 60,000 lux. If we allow 30% for loss within the Martian atmosphere by absorption, scattering, and reflection, then the remaining 40,000 lux are far above the photosynthetic light minimum. Therefore, indigenous green-plant life of the type we know is conceivable on Mars. And if Mars some day should be contaminated with green terrestrial microorganisms, there is no question that they could exist on Mars as far as the photic environment is concerned.

I should like to conclude this discussion with a comparison. The light minimum for photosynthesis in the oceans and lakes is placed at about 200 m below the surface; the highest photosynthesis activity occurs in the upper 10 m, as indicated by complete saturation of the water with oxygen or even an excess of oxygen. Here lies the ecosphere for sea animals concerning light conditions and food. But those living in the aphotic depths of the ocean depend on what sinks down from the rich table in the euphotic near-surface layers. With this comparison we have returned from our theoretical space exploration to the sea, with which we started this discussion.

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GLOSSARY

Photometric Terms and Units

Illuminance	Luminous flux incident on unit area. Unit: Lux, footcandle
Lux (lx)	Synonym metercandle: An illuminance of 1 lumen/m^2.
Footcandle (fc)	Illuminance of 1 lumen/ft^2.
Lumen (lm)	The luminous flux emitted through a unit solid angle (one steradian) from a point source of one candela.
Luminance	(photometric brightness): Luminous intensity of any surface in a given direction per unit projected area of the surface viewed from that direction. Unit: nit
Nit (nt)	A luminance of 1 candela/m^2.
Candela (cd)	Unit of luminous intensity. Newly defined and internationally accepted candle.

SPACEFLIGHT SITUATION:
SENSORY-PHYSIOLOGICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

The situation encountered in space by man is the result of the strange physical environment itself and the process of movement to, through, and return from this environment. In my discussion I would like to confine myself to a sensory physiological analysis of human performance during the state of weightlessness, the most characteristic feature in motion dynamics in space. This has been studied in a free-fall (1), on a zero-gravity tower (11), and especially during parabolic flight maneuvers, a method suggested 10 years ago (6, 9).

Thousands of such parabolic flight maneuvers in two-seated jet aircraft and in larger aircraft, during which the state of weightlessness for maximally 1 minute can be produced, have shown that sensory motor performance is not noticeably disturbed (7, 8, 15, 19). At first glance this seems to be surprising, since weightlessness is an extra-terrestrial exotic condition, but a detailed examination of the various sense organs involved or not involved in sensory motor performance gives the answer.

The human body is equipped with several sense organs which inform us about, and exert reflex control upon, the equilibrium of our body as a whole, at rest and in motion, and about the position and movement of the limbs. The nerve endings in question react to mechanical forces or stimuli; they are therefore referred to as <u>mechanoreceptors</u>. Those mechanoreceptors responding to stimuli that are related to the gravitational force of Earth, are called <u>gravireceptors</u> (or graviceptors) in the physiological literature (18). This term is acceptable--not in the sense that we are able to sense gravitational-field forces, but rather that we can perceive weight, a physical attribute of matter resulting from gravitational forces. In publications dealing with this kind of sensory nerve endings, the gravireceptors of the centrally located labyrinth, or more precisely of the otolithic portion of the vestibular organ (contained in the bony cavity of the inner ear), are discussed primarily. In contrast, little attention is given to those mechanoreceptors or gravireceptors that are found in the <u>skin</u>, in the <u>skeletal muscles</u>, and in the <u>connective tissue</u> (2, 3, 13, 16, 17).

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These peripheral (extralabyrinthine) gravireceptors, their physiological function under normal gravitational conditions, and, finally, their function under the condition of zero gravity as it is encountered in spaceflight, therefore, will be in the center of this discussion.

The Pressure Sense of the Skin. The best known peripheral mechanical sense organ is that of the pressure (touch) sense of the skin, responsible for the so-called tactile and pressure sensations. The nerve endings are nervous plexuses around the hair follicles and the Meissner corpuscles in the skin of the tactile surfaces such as the palms and the soles. The density of these presso- or tangoreceptors is about 20/cm^2 on the hairy skin and more than 100/cm^2 on the palms and soles, altogether totaling more than half a million (5).

The adequate stimulus for these sensory nerve endings is not the pressure as such, but rather a change in pressure resulting from a mechanical deformation of the skin.

The pressure-sense nerves show rapid adaptation; after fractions of a second or a few seconds, the sensation fades so that slight changes in the pressure at the same skin area will elicit new sensations.

With a reaction time of about 160 milliseconds, the pressoreceptors play an important role in the perception of the position and movement of our limbs and of the whole body (walking, etc.). During swimming, water resistance evokes pressure sensations in the skin. In flying an aircraft, the importance of the pressure sense lies in the sensations produced in the skin contact with the seat, giving information about accelerations in curves and up and down movements to which the body is passively subjected. Its importance for active movement lies primarily in handling the controls of the aircraft. In most of these functions the pressure sense is associated with two other sensory mechanisms; the muscle sense and the posture sense.

The Muscle Sense. The receptors of the so-called tension sensation of the muscles perceived during passive and, especially, active movements, are the so-called muscle spindles, found in all those muscles which fixate and move body masses, particularly those of the limbs. They are not found in the diaphragma and the eye muscles, the function of which has nothing to do with gravity. The muscle spindles inform us of our body weight and the weight of objects resulting from gravitation and accelerations. They also serve as receptors of the myostatic reflexes such as the patellar reflex, etc. They are therefore the receptors of a gravisensory system and at the same time of a gravireflex system.

The Posture Sense. Besides the pressure sense of the skin and the tension sense of the muscles, there is a third peripheral component in the sensomotoric control of our body and its parts: the so-called posture sense (4, 5), which has probably some relationship to the postural reflexes described by R. Magnus (12). The nerve endings are in all probability the Pacinian corpuscles which are found at strategic places throughout the connective tissue surrounding and penetrating the muscles. They may be stimulated mechanically when the muscles change their form during the movement. These nerve endings, which are also found in the peritoneum, are large enough to be seen with the naked eye, but their specific function has been somewhat overlooked. The reason may be that in contrast to the muscle sense and, especially, the pressure sense, the excitations of the posture-sense receptors do not fully exceed the threshold of consciousness; they remain more or less subconscious.

Thus the perception of the position and movement of our limbs seems to be thrice secured; namely, by the pressure sense of the skin, the muscle sense, and the posture sense. These three peripheral mechanical sense organs together constitute, therefore, a functional system in the perception and sensomotoric control of position and movement of body parts. This peripheral extralabyrinthine system and the labyrinthine otolith organ form a larger functional unit, a statokinetic control system--integrated in the process of the perception and sensomotoric control of the position and movement of the whole body.

TABLE 1. MECHANO-SENSORY STATOKINETIC CONTROL SYSTEM

Labyrinthine system	Extralabyrinthine (peripheral) system
Vestibular organ	Pressure sense
	Muscle sense
	Posture sense

This latter function is associated with the eye by nerve connection with the vestibular apparatus. Equilibrium and locomotion, therefore, depend on the coordinated functions of the mechanoreceptors (gravireceptors) plus photoreceptors (3, 17).

Not too many comparative histological data about the phylogeny of the peripheral mechanoreceptors are found in the zoological literature; however, what is known demonstrates in an impressive manner their function in the various environmental media.

The dominant creatures in the hydrosphere, the fish, possess on both sides of their body a long nerve, the so-called lateral organ, that is a highly developed mechanoreceptor device. It enables them to sense pressure waves, water currents, etc. This is the sensory part of their biohydrodynamics. Today we observe astounding fishlike performances by deep-sea divers, in which the peripheral mechanosensory nerves play an important role.

Birds possess nerve plexuses around the quills of the flight feathers and muscle spindles, also Pacinian corpuscles in the connective tissue of the wings, by means of which they sense the slightest atmospheric currents and air resistance, and which makes eagles, seagulls, and other birds masters in soaring. We find an approximation to this in human control of a glider plane. Pigeons in which the posterior roots of the spinal cord (through which the sensory impulses from the skin and muscles of the wings are transmitted) have been bilaterally dissected, are not able to fly although their motor pathways are intact (18). This illustrates the importance of the sensory part in their bioaerodynamics.

And now in spaceflight with no environmental resistance, man enters the realm of the laws of astrodynamics, or celestial mechanics. To understand his sensomotoric performance during weightlessness, let us briefly remember the general fundamental functions of our sense organs. They have an exteroceptive function as they react to external stimuli and inform us of the outer environment, and an interoceptive, or proprioceptive, function as they perceive internal conditions, such as pressure, tension, position, etc. The exteroceptive sense organs, par excellence, are the eye and ear. Muscle spindles and Pacinian corpuscles are fundamentally proprioceptors. The labyrinth organ and the touch sense lie somewhere between these two extremes.

In the gravity-free state, with gravitational stimulation absent, the exteroceptive function of the mechanoreceptors is eliminated; their proprioceptive function is not. Since the peripheral mechanoreceptors are predominantly proprioceptive, there is no reason why precision in performance of hands, arms, and legs should be disturbed. Numerous tests in parabolic flight maneuvers actually have verified this, as mentioned above. It is difficult indeed to see how the muscle sense, for instance, could be affected by zero gravity at all. In contrast, it lies in the nature of the design of the otolith organ, which is primarily responsible for the perception of position and locomotion of the whole body, that its function in both categories is eliminated in the gravity-free state. It follows, then, that its partner in position and motion control of the whole body, the eye, has to take over this function alone. Thus the photoreceptors are the only receptors that can furnish the astronaut the information about his position and movement in space. This is in sharp contrast to the life of the blind deep-sea fish which depend, in this respect, exclusively on their mechanoreceptors.

Now in any geocentric orbit, which is conceivable up to 1.5 million km--the extension of Earth's potential satellite sphere or gravisphere, there is physiologically no gravitational reference point and no gravitational geocentric feeling on the part of the astronaut. This feeling that he belongs gravitationally to Earth will return as soon as the spacecraft dips below 200 km; i.e., across the mechanical border of the atmosphere. There it gradually receives aerodynamic support; and with this, weight returns. At what fraction of 1 g the sensation of body weight becomes noticeable, or what the threshold is for perception of weight, is a question which may some day be answered by returning astronauts.

This whole discussion is based on the assumption that man can tolerate zero gravity over longer periods of time. We are not yet sure of this, however, because experimental data on man are still not available.

In case zero g cannot be tolerated over longer periods of time, we have to provide for artificial gravitation. The question is: how large or small a fraction of g is needed to overcome any disturbances and to give the occupants of the vehicle the necessary feeling of weight--in other words, to bring about a kind of gravitational normalization of life. This would be an interesting question for astronauts orbiting around Earth. Concerning extended operations (for instance, to the Moon or to Mars), it would be logical and practicable to reproduce, by means of rotation of the vehicle, the gravities found on these target celestial bodies; that is, 17% of 1 g for the Moon and 38% for Mars.

Table 2 shows the period of rotation necessary to produce 1 g at radii of 5, 10, and 20 meters (O. L. Ritter). In the second and third part of this table you find the respective values concerning Martian and lunar gravity. It might be that these provisions are not necessary; that is, if zero g over a longer period of time does not cause disturbances. But we in the medical sector of astronautics must be prepared for all possibilities.

TABLE 2. ARTIFICIAL GRAVITY BY ROTATION

Gravity	Radius (m)	Period of revolution (sec)
1 g	5	4.5
	10	6.3
	20	9.0
.383 g (Mars)	5	7.2
	10	10.0
	20	14.5
.165 g (Moon)	5	11.0
	10	15.6
	20	22.1

Another way to produce artificial gravity in a spacecraft is that of slight continual linear acceleration by some kind of propulsion. With the present and foreseeable propulsion systems, however, the attainable gravity would be rather small, perhaps below the threshold for the sensation of weight; yet it would have great advantages in that it would shorten the duration of a trip to the neighboring planets tremendously. For instance, applying 0.01 g continuously would shorten the time of a trip to Mars from about 9 months to 20 days, and applying 0.1 g would shorten it to 7 days (O. L. Ritter). This is the formula for interplanetary operations; namely, to change from a minimum-energy orbit to a minimum-time orbit which space medicine must suggest to astronautics. In this way, many of the neurophysiological problems would be solved.

In conclusion, I would like to touch upon two misconceptions occasionally expressed in conversations and also in the astronautical literature. The first one is this: The orbiting of a vehicle around Earth is often described as a constant falling, and the opinion has been expressed that this might produce the nightmare of a sensation of endless falling. If we consider the function of the otolith organ, we must come to the conclusion that this is not so. The astronaut will have the sensation of falling perhaps for only a few seconds when he enters the gravity-free state. Thereafter this sensation should cease because the otoliths have attained a new equilibrium. All of this means that falling in the physical sense is not necessarily associated with a physiological fall sensation lasting all the time.

Another misconception is encountered occasionally. If a vehicle is in an elliptic geocentric orbit, it increases its velocity coming from the apogee to the perigee. This means the vehicle is accelerated; and the opinion is occasionally expressed that during this phase of the trajectory, there should not prevail a condition of zero g, but rather a certain amount of weight should result. This is not the case, because the sum of all forces (gravitational and inertial) acting upon the vehicle and the body of the astronaut in any phase of the trajectory, outside of the aerodynamically effective atmosphere, is zero (14).

The state of weightlessness is often compared with floating in water, and the sensory and physiological effects are even identified. While both states have certain features in common, in other respects they differ. Considered from a sensory physiological point of view, this is the situation: During passive floating in still water, the pressure from the supporting water is evenly distributed over almost the entire surface of the body; therefore, sensations from the presso-receptors of the skin either do not occur or remain below the threshold of perception. And if the body has no foothold, tension sensations from the leg muscles are more or less absent. In contrast, when standing on solid ground or walking, the cutaneous contact area with the supporting medium is relatively small; the pressure stimulation per unit area of skin resulting from the body's weight is great, and pressure and muscle sensations therefore dominate the picture. The absence, during floating in water, of sensations from the peripheral mechanoreceptors may be one of the reasons that induce people to believe that the consequences of this situation are identical with those of the state of zero gravity.

In brief, during immersion in water, the surface forces acting upon the skin of almost the whole body are sensory physiologically ineffective. But (and here is the difference) gravity as a volume force acts, of course, upon the whole body, including the otoliths--a fact which gives the deep-sea diver the capability of orientation. In spaceflight, all the mechanoreceptors are eliminated as far as their exteroceptive function is concerned. This is the main sensory physiological difference between weightlessness and floating in water (10).

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SPACE ENERGIES: SUMMATION*

Hubertus Strughold, M.D., Ph.D.

When the Spaniards and the Vikings, half a millenium ago, ventured to the West, they depended on the energies of the hydrosphere and atmosphere. They could benefit from them, but also had to protect themselves from them. Their major problem lay in the realm of nutrition, as evidenced by the occurrence of avitaminosis in some of the expeditions--understandable because of the deficient knowledge in the fields of nutrition and metabolism at that time. Today, astronautics faces the problems of safeguarding a space traveler on journeys leading far away from our hydrosphere and a breathable atmosphere, through a thinly dispersed plasmatic, nearly vacuous medium, and ending on the surfaces of other celestial bodies.

I consider it a special privilege to sum up this Symposium on the energies of space from the viewpoint of bioastronautics.

First, in no other field is there a greater need for clear definitions and units of measures than in the field of energies, especially in the question of types of radiations, dose, etc. In the field of gravity the introduction of the kilopond as counterpart to the kilogram seems to me useful for clarification of the mass and weight concept, to mention only a few points.

Now, beginning with the human body as an energy converter under the conditions of spaceflight, we may assume for the metabolic rate of an astronaut of 70 kg weight, a value in the order of 2800 kg cal/day. Actually, in the weightless state, as related experiments of Dr. Graveline in a water tank indicate, it may be as low as the basal metabolism of 1800 kg cal/day, or even lower if we ignore psychological effects such as tensions, etc. However, such situations lead to muscle asthenia and general weakness. Countermeasures must therefore be taken in the form of gymnastics with special space gymnastic equipment to increase the metabolic rate to a healthy metabolic energy level; and with 2800 kg cal/day, we would probably not be too far off. The same would be necessary on the Moon and Mars, corresponding to their lower gravities. The metabolic rate of 2800 kg cal/day requires about 500 g solid food: protein, fat, and carbohydrates in proper physiological proportions and minerals, in addition to 2 liters of water. The heat production of the astronaut

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at this metabolic rate equals that of a light bulb of 100 watts. This heat influx into the spacecabin is a factor in the cabin's temperature control which cannot be ignored. It is the only energy the astronaut contributes to the complex of the intracabin environment. All others come from the outside.

The extracabin energy type that deserves most attention with regard to both utilization and protection is solar electromagnetic radiation. Within a certain range of intensity this type of radiation is life-supporting and useful; on both sides of this range it is detrimental to life. This refers to temperature control of the cabin, to vision, and to its role in photosynthesis.

Concerning cabin-temperature control, the heat irradiation in the region from Mars to Venus may well offer the optimum range utilizable in this respect. In the direction of Mercury, beyond the maximum that could be handled from an engineering point of view, we certainly would run into a solar-heat barrier. In the direction toward the outer planets beyond the minimum, artificial heating by nuclear power has to replace the warming Sun.

With regard to vision, as long as the Sun appears as a disk--larger than 3 minutes of arc, and that is the case as far as Saturn--there is the danger of retinal burns if the astronaut looks directly into the Sun. This requires eye protection by means of automatically functioning, light-absorbing glasses. At the distance of Pluto, solar illuminance is just high enough for reading; and at three times this distance, it drops to the minimum required for color vision.

Photosynthesis would require attenuation of sunlight beyond Venus to prevent solarization of the biotic material; the minimum limit for photosynthetic utilization of sunlight may be found somewhere between Mars and Jupiter, where it decreases to some 20,000 lux. But all this depends on the efficiency of the photosynthetic system. From here on, light production by a nuclear powerplant would be required for photosynthetic recycling; this would make the spacecabin a sun-independent, or an autark, ecological system.

Now in this whole picture of solar electromagnetic radiation we must not overlook the shadow regions caused by the planets and moons; namely, the umbrae and penumbrae. The umbra cone is a dead region as far as utilization of solar light is concerned; and in the Earth's penumbra, solar illuminance drops gradually from about 140,000 lux at the outer rim to zero lux at the border adjoining the umbra. Earth's full shadow cone reaches as far as 1,340,000 km--3.5 times the distance of the Moon. That of Jupiter extends to 80 million km.

Generally in space there is heat transfer only by radiation, resulting in an equilibrium temperature of a space vehicle. In the umbral regions there is no heat transfer from the Sun but some from the planets; this is in contrast to the situation in Earth's atmosphere, where we have heat transfer through solar rays, through conduction and convection.

With regard to the location of the planets in the solar radiation field, I would like to mention only briefly that there is a zone which we might call the zone of golden orbits; i.e., the zone of plenty--not too much and not too little of solar radiant energy. Earth occupies "the" golden orbit par excellence in our solar system; next in order are Mars and Venus. Mercury receives too much radiant energy, and the outer planets receive too little. They are the "have nots" in this respect, or the "under-privileged countries" in our solar system. Other stars may show a similar ecological pattern in their planetary families. So much for solar electromagnetic radiation.

There seems to be no possibility of putting the geomagnetic-field forces to use for manned spaceflight, nor do they per se in any way affect the astronaut's health; they enter the bioenvironmental picture of space only indirectly insofar as they largely determine the spatial distribution and flux of energetic-charged particles by deflecting and trapping action. The radiation belts and the latitude cutoff of low-energy particles are the work of the geomagnetic forces. They may also bend the jet streams of solar plasma. According to Russian magnetometer recordings in their Space Probe II, the magnetic field near the Moon's surface is 400 times weaker than that on Earth's surface--too weak to have any significant effect upon particle fluxes; in other words, no particle-ray variations around the Moon. About Mars, nothing is known. But Venus should have a strong magnetic field, as must be concluded from polar light occasionally observed by astronomers. Polar lights are caused by bombardment of atmospheric material by energetic particles. The accent of our interest in particle radiation lies on the side of protection against them and not on that of utilization, which is difficult to imagine at present.

Drugs of inorganic and organic nature so far seem to offer no adequate protection against radiation hazards. The solution then is to avoid specific danger zones and times of increased danger and to apply shielding.

In case of manned satellite flight, we can assume that for the near future the arena for this type of spaceflight will not exceed the altitude of 1000 km, which is the inner border of the inner zone of the Van Allen radiation belt. These low orbits, as we might call them, pose the least radiation hazards. Orbits in the altitude range from 1,000 to 80,000 km, which cover both zones of the great radiation belt and which we might call medium orbits, are too dangerous unless heavy shielding is used and, therefore, are prohibitive at present. The high orbits in deep space beyond the radiation belt probably are not very practical or useful for manned satellite operations.

The matter is somewhat different when the vehicle merely passes through nearby space into deep space on flights to the Moon or into interplanetary space. Avoiding the equatorial latitudes and choosing the polar regions as exit routes is one way to get around, or at least facilitate, the problem of shielding. Dashing as rapidly as possible through the radiation belts is another.

In the presatellite time, suggestions concerning shielding from energetic particles were based on pure speculations and hypotheses. Now the propositions can rely on theories based on actual facts learned by numerous space probes. They take into account the atomic number and energy of the primary particle rays, their spatial variations as evidenced by the radiation belts, the temporal variations as manifested in jet streams of solar plasma observed after solar flares, and the secondary rays produced in the shielding devices and cabin shell.

All in all, the radiation dose inside the cabin has to be kept below the maximum permissible level, which is determined by a significant health and performance decrement.

Concerning hits by highly energetic cosmic particles, we must also consider the chemical composition of the human body, which is a light-element construction. Its specific weight lies between that of water and of the Earth's crust. This can be regarded as fortunate with respect to star events, as the result of a collision of a cosmic ray particle with an atomic nucleus in the body is not so hazardous as if our body were composed of heavier elements.

Shielding from radiation probably will be combined in one way or another with that from meteorites (that is, with meteor bumpers) to prevent puncture of the cabin. This latter should not be too difficult a problem. More complicated may be prevention of erosion by micrometeoric material, which affects the reflectivity of the cabin's outer shell and the transparency of optical surfaces.

The kinetic energy and trajectories of meteoric material are determined by the gravitational field except for very small particles below 0.5 μm diameter, the movement of which is also affected by light pressure and, if charged, by magnetic fields. These submicronic particles are called dust. Dust and meteoric particles are concentrated in the ecliptic plane. They are also denser around Earth up to about 1.5 million km, or 1 million miles. This happens to be the extension of the area in which the gravitational forces of Earth prevail over those of other celestial bodies. This gravienergetic spatial unit, or gravisphere, is the potential satellite sphere which embraces the relatively small gravisphere of the Moon.

Knowledge of these gravitational domains in the solar gravitational space is useful for a better understanding of the distribution, velocities, and trajectories of all kinds of material in space, and of the interaction of the kinetic energy of space vehicles, and gravitational forces. The duration of space missions is determined by these two forces. An interplanetary mission based merely on the escape velocity from the geogravitational field takes many months. A shortening of these durations by suitable propulsion systems is preferable or even mandatory for reasons of logistics, efficiency of the life-supporting systems, the psychophysiological nature of the human creature, and last but not least, for reasons of the duration of the astronauts' exposure to the various hostile space energies, especially particle radiations.

A minimum time orbit versus minimum energy orbit must be regarded as the "Suprema Lex" in bioastronautics, but it has also its limitations; namely, with increasing speed approaching that of light, the collision energy of any particle would become disastrous because of the kinetic energy of the space vehicle itself.

As we have seen during this symposium, identification of the various space energies, their possible utilization, and degrees and means of protection are the research tasks in the field of exploration of space energies. By and large, of the latter two, protection seems to deserve most of our efforts, because the life-destructive character of the space energies prevails. Nevertheless, all three aspects are vitally important as the keys for man's entrance into space.

I would like to conclude this summation with a friendly note about the energies of space. From the standpoint of space medicine, which is responsible for the astronaut's safety and health, the 1958-discovered geophysical phenomenon, the Van Allen radiation belt, is always looked upon with grave concern as a life-endangering or life-destructive biocidal obstacle on the way to the stars. But I would like to mention, also, that from an astrobiological point of view, it might have played an important life-supporting or even life-producing role. For the past 25 years it has been theorized that some 2 billion years ago, under the influence of the ultraviolet part of solar radiation and/or lightning in the protoatmosphere of the Earth, amino acids were produced and that this prebiotic material represented the nutritional substrate of, or led to, the origin of life. Now it is well conceivable that portions of the Van Allen radiation belt have played a part in this process.

The horns of the outer belt which dip into the atmosphere in the subarctic regions, could have been, so to speak, the sparkplugs for the origin of life, especially effective after solar flares. If this hypothesis is correct, then the origin of life would have been the result of a marriage between the energies of solar plasma and protoatmospheric matter, and only planets with magnetic fields and orbiting in proper distances from the Sun would have life-producing capabilities. This also applies, of course, to other stars with planetary families. The hypothesis could be tested in a satellite of the Echo type filled with ammonia, methane, and water vapor moving in an orbit at the altitude range of the Van Allen belt. This would be a repetition in actual space of an experiment carried out by Dr. Stanley Miller 7 years ago in the laboratory, who could produce amino acids in a chamber filled with gas of protoatmospheric composition and exposed to electric discharge. It would also be a recapitulation on a small scale of the gigantic paleobiologic drama that took place in archaic times on Earth in the contact zones between its primordial atmosphere and the space energies emitted from the Sun and concentrated by the geomagnetic field.

SENSE AND NONSENSE OF MANNED SPACEFLIGHT:
AN OPTIMISTIC-REALISTIC APPROACH*

Hubertus Strughold, M.D., Ph.D.

When important discoveries and inventions are made, there is always some speculation about their developmental potentialities. Usually these developments take place in a gradually rising curve of progress, but recently the pace of progress has become faster--for instance, in the field of atomic energy. And in the most recent field of technologic and scientific development--rocketry and space exploration, we have seen during the past 5 years such fantastic jumps and spectacular achievements that we have become spoiled, space spoiled. Before that time there was no artificial Earth satellite in the sky. Today there are, or have been, more than 30 such space vehicles, including lunar and solar rockets.

Progress has taken on an explosive character, like the population explosion on the rabbit-blessed continent of Australia. In a kind of space fascination, many people now consider everything possible. This was not so in the first 12 years after the war, in the presatellite phase of rocketry. There was considerable skepticism. The word "space" was taboo, particularly at high official places, but not so in the Armed Forces. For the Air Force, spaceflight was, and is, nothing else than a logical extension of atmospheric flight.

I speak now from my own experience in the field of space medicine, which studies the possibilities of manned spaceflight. As you know, we have had a department with that name at Randolph Air Force Base since February 1949. Special credit must be given to our public information officers at that time, and to the people of the press, radio, and television, who took particular interest in this matter and informed the public of the advent of manned spaceflight, and of the strange activities in that, so to speak, out-of-this-world department. This support has been very beneficial to us because in those first horse-and-buggy years of scientific space activities, we had to fight for recognition and against ridiculization. I would like to illustrate this by a few stories.

In the spring of 1949, I, accompanied by three coworkers, had a conference with Dr. Werner Von Braun, at Fort Bliss, near El Paso, Texas,

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*Presented at the banquet of ATC Information Conference at Randolph Air Force Base, Texas, 23 January 1961.

to discuss plans to shoot a monkey in a V-2 into the fringe zone of space. This plan included all kinds of bioinstrumentation, even telemetry. I remember when I was, the next morning, in the lobby of the hotel, there was a liaison official who told some civilian visitors from Washington, "We have here a fellow who would like to fly to the Moon." He had in mind Von Braun. "And yesterday, we had a visit from some doctors from Randolph Field who plan to shoot a monkey into space." They were amused. The time was just not ripe for such extraterrestrial undertakings.

In the fall of the same year, when I was for several days in Washington, I was asked by a lady who was in charge of the Radio Program for the Walter Reed Hospital, and who had heard that we had deep in the heart of Texas a department of space medicine, to make a speech for the patients over the in-house radio about a flight to the Moon. I told her that I would prefer to talk about the problems of space medicine, but she announced it in the bulletin under the more attractive title "Space Medicine and a Flight to the Moon." The next day when we started the interview in the hospital's radio room, which was separated by a glass wall from the lobby, I noticed that about a dozen patients came down in the lobby and watched the program. They stared at me, and I felt almost embarrassed because I had the feeling that they thought I was crazy. I gave first a 10-minute discussion about the problems of space medicine, thereafter she asked questions about the medical problems involved in a flight to the Moon. The patients in the lobby listened very attentively and seriously, and after the program was over they disappeared. When we left the soundproof radio room, I asked the receptionist in the lobby, "Please, can you tell me from which ward these patients came." She answered with a sympathetic smile, "I am very sorry, Doc, they all came from the Psychiatric Ward." But today, we have a spaceflight committee in the House of Representatives and in the Senate, and almost all governments--for instance, in Paris, Bonn, and Rome--have some kind of a committee for astronautics to watch the development in this field, including projects dealing with flight to the Moon.

When in the presatellite years, I gave my regular lecture, "Man at the Threshold of Space Flight," in the primary course for flight surgeons at the School of Aviation Medicine, for the first 5 or 10 minutes the students smiled and I had the feeling that they considered it a continuation of the cocktail party of the preceding evening. But, today, one does not see smiles, and I have to show from time to time a cartoon to instill humor into the discussion.

Such is the situation today. In the opinion of most people, the potentialities of manned spaceflight seem to be limitless and velocities have become meaningless. Everything is now taken for granted, even a flight to one of the neighboring stars. From a medical point of view, this is not so. Some of the projects which are proposed in the astronautical literature make sense, and are indeed a unique challenge for space technology and space medicine; but some of the suggestions of some eager space beavers are unrealistic and just do not make sense. To elaborate on this more in detail is the topic of my discussion, but I shall concentrate solely upon the factor of safety and not on the question "Why manned spaceflight?" which has been frequently discussed recently.

To have a kind of frame of reference, we need a clear definition of space for a classification of the various kinds of space operations and the pertinent space vehicles. A description of space with its topographical environmental differences--in other words, a geography of space, or more to the point, a spatiography--must be based on the ecological and gravitational conditions. In this way, we get the following picture. We can differentiate between the space-equivalent regions of the atmosphere in which the various space factors gradually enter the environment, beginning at about 20 km and extending to about 200 km. Here the sensible atmosphere ends and true space begins. This true, or outer, space is by no means uniform; it shows considerable topographical variations and temporal fluctuations in its conditions.

First, in the vicinity of Earth, space shows some peculiarities caused by the solid body and atmosphere of Earth, and especially by its magnetic field which is responsible for the existence of a huge belt of trapped particle rays extending from about 800 to 80,000 km. We can call this specific region "nearby space." Beyond this distance, we enter open, or deep space. This deep space is still very much under the influence of Earth; namely, under its gravitational influence. The region where this effect is predominant extends to 1.5 million km. This gravitational domain of Earth, or its gravisphere, is the gravitational planetary space of Earth, or the terrestrial space. Beyond its border we enter interplanetary space, in which a space vehicle comes under the predominant influence of the Sun. From here, a transit trajectory may carry a space vehicle into the gravitational territory of one of the neighboring planets. Finally, the solar space, or more accurately, the gravitational space of the Sun, comes to an end far beyond Pluto, where it blends with that of the nearest star. The gravitational planetary space of Earth contains, of course, the gravisphere of the Moon, which extends to about 60,000 km from its center. Such is the picture of a subdivision of space, which we can use as a basis for our discussion about whether or not the various pertinent types of space operations make sense.

By sense, and nonsense in this respect, I mean whether or not manned space operations are conceivable and realizable as seen from the standpoint of the present and foreseeable state of the art and knowledge in the physical and especially biological sciences. With regard to the latter, this depends essentially on the ecological conditions of the space environment and on the durations of the flight operations and their medical implications.

Now, first, space-equivalent flight is already history. The high-altitude flights in high-performance jet- and rocket-powered craft (such as the 100 series, the X2, X15, U2, and the coming B60) are flight operations of the space-equivalent type if they exceed the 20-km level. These vehicles flying in the range of aeronautical speeds--subsonic, supersonic, and hypersonic--are aerospacecraft. I would like to mention at this point that the International Aeronautical Federation at its last meeting (1960) in Geneva has decided to call a vehicle capable of flying above 100 km (62 miles), which is the so-called Von Karman line, a space vehicle. This is the altitude where aerodynamic lift and navigation by control surfaces end.

Above 200 km, where air resistance and drag decrease to such a level that satellites have a worthwhile lifetime and where the aeronautical speeds become meaningless, we speak of astronautical, or cosmic, velocities. Three kinds of these are differentiated: the orbital velocities as observed in flights around Earth and the Moon, the escape velocities from Earth's gravisphere and from those of the other planets, and the escape velocity from the Sun's gravity or generally from those of the stars.

The circumterrestrial orbital velocity, an example of the first category of astronautical velocities, leads to satellite flight. Several years ago in discussions of manned satellite flights, no difference was made concerning orbital altitude and inclination, but since discovery of the Van Allen radiation belt, we know that there is only a narrow region relatively safe for manned satellite flights, extending up to an altitude of 600 km and to the 40° latitudes, north and south. The radiation hazards in this corridor are not significantly greater than those of a medical technician working in an X-ray laboratory.

For the Air Force, this satellite arena of low orbits is of great importance. At an orbital altitude of 500 km, a territory of 5000 km in diameter is within optical reach. The Russians have apparently chosen the altitude of 320 km for their standard orbit. From a distance of about 6 Earth radii, we can overlook half of the planet, but at this distance we are in the outer zone of the radiation belt. The same is true for the much discussed 36,000-km high stationary satellite, which has a period of revolution that corresponds with the rotation period of Earth.

Orbits located in the Van Allen belt, which we call medium orbits, are presently the forbidden orbits for manned satellites. For lunar, interplanetary, and planetary missions, the existence of this radiation belt makes it advisable to use the polar regions as exit and reentry routes, unless dashing with very high velocity straight through the radiation belt, plus proper shielding, keeps the radiation intensity below the maximum permissible dose level.

In the deep-space region beyond the Van Allen belt, a satellite would be exposed solely to the general omnidirectional flux of cosmic rays, and of course to the dangerous temporary winds of solar plasma blown into space after solar flares. These so-called high orbits are probably not of practical value.

You see, the results of space exploration, especially those obtained in the U.S. research satellites and space probes, have changed our concepts about the trajectory pattern of space operations in the vicinity of Earth. Several years ago there were no restrictions; now we differentiate between permissible and forbidden regions. Such rules probably do not apply to the environment around the Moon, which has--according to Russian recordings--a magnetic field 400 times weaker than that of Earth, and has therefore in all probability no radiation belt. This might be different around Mars and certainly around Venus.

Lunar, interplanetary, and other planetary space operations require escape velocity, the second astronautical velocity. In addition to the ecological conditions of space in such extended undertakings, the duration of the flight attains increasing importance.

First, the ecological conditions in interplanetary space show tremendous differences as a function of the distance from the Sun. The main factor in question is solar electromagnetic radiation with its ecologically important sections: heat rays, visible rays, and the ionizing short-wave rays--ultraviolet and X-rays.

Let's consider only heat radiation. At the top of our atmosphere a spaceship receives 2 cal/($cm^2 \cdot$min); i.e., twice as much as we maximally receive on the surface of Earth on a hot sunny day. At the distance of Venus, it doubles; and Mercury receives more than 6 times as much, or about 13 cal/($cm^2 \cdot$min). In the region of Mars it drops to less than 50%, in that of Jupiter to 4%, and in the remote region of Pluto to 0.06%. What effect this might have upon the temperature control of the cabin of an interplanetary spaceship can best be illustrated by an asteroid which comes very close to the Sun and therefore has been called Icarus by its discoverer (W. Baade, Mt. Palomar, 1949). But its very eccentric orbit, which has a period of revolution of 409 days, carries it also very far away from the Sun. It has been estimated that the surface temperature of Icarus at its perihelion--some 30 million km from the Sun, or halfway between Mercury and the Sun--rises to some 500°C; and at the aphelion, between Mars and Jupiter, it should drop somewhat below the freezing point of water. This natural celestial body shows us what we can expect for an artificial celestial body in the hyperthermal (hot) and hypothermal (cold) regions of the solar space.

In the hyperthermal intra-Venusian and certainly in the intra-Mercurian space, astronauts would run into a kind of solar heat barrier. A penetration into the hypothermal regions beyond Mars and Jupiter would find the Sun's rays too weak for use in cabin temperature control, and would then require a Sun-independent, nuclear heating system. The same would be true with regard to using the light for photosynthetic recycling of the intracabin atmosphere and metabolic endproducts of the astronauts. Only space operations within the more or less temperate range from Venus to somewhere beyond Mars offer conditions that pose not too great difficulties from a bioengineering and air-conditioning point of view.

With these more and more extended space operations, the time factor, or the duration of the flight, moves from the background into the focus of medical interest with regard to the time of exposure to the various space conditions, the efficiency of the life-supporting systems, and the reactions of the human creature to the conditions of confinement and isolation.

Most of the interplanetary and planetary projects involve considerable durations if based on minimum-energy trajectories. A flight to the Moon and return in this way is a matter of less than a week. Medical problems would probably not be too difficult. A flight to Mars, based on a low-energy orbit, however, requires a time of more than 8 months. The experiences gained in spacecabin simulators indicate that flights of such durations in a sealed compartment under the conditions of confinement and isolation might meet with the greatest difficulties. Therefore, a shortening of the duration of interplanetary missions to medically acceptable magnitudes must be strived for by suitable propulsion methods, which might include higher initial velocity or continuous slight acceleration during the journey. The formula: minimum-time orbit versus minimum-energy orbit should be regarded as a "physician's prescription" to astronautics. The size of the cabin and the comfort that can be offered to the astronauts, of course, play an important role in this biotechnical problem.

Continuous slight acceleration, if it can be maintained long enough, leads to very high velocities, such as the third cosmic velocity; i.e., escape from the solar space, and ultimately approaching the speed of light. But not every velocity envisioned for interstellar flight is acceptable from a medical point of view. Velocities in higher fractions of the speed of light can become a limiting factor by a speed-induced intensification of certain hazards of the space environment--namely, increased collision energy of meteoritic material, dust, and high-energy particles. This and other reasons may make interstellar flight highly problematic.

This should not prevent us from speculations about the relativistic problems encountered in interstellar flight. They represent a wonderful platform for new inspirations and ideas which someday (or better, some century) might be realized. This has been the case with speculations in science fiction, which by no means should be identified with nonsense. Actually many of the topics in science fiction make or have made sense.

In all probability then, if we adopt an optimistic, realistic attitude, the operational range of manned spaceflight will for a long time to come be confined to the celestial bodies of our home solar system. But even this more modest goal, even if limited to the neighboring celestial bodies--Moon, Mars, and Venus--will be one of the greatest biotechnical achievements in human history.

Now, what can we expect and what can we do on the neighboring celestial bodies? Colonizing the Moon in the sense of populating the Moon is lunar nonsense, but the creation and maintenance of a Moon base is absolutely in the realm of feasibility. The same can be said about Mars and may be the case on Venus if this planet is not too hot, but a base on Jupiter has to wait several billions of years, until it has moved closer to the Sun and its hydrogen and ammonia atmosphere has been transformed by solar ultraviolet radiation into an oxygen and oxidized atmosphere. By that time Earth probably will have plunged into the Sun and some Earthlings of the 10^9 generation from now can start it all over again as Jupiterites.

Concerning life on the neighboring celestial bodies, such as Mars, it is absolutely feasible and even probable that the astronauts find there the same kind of life as on Earth, based on carbon as the basic structional atom. But, corresponding to the severe climatic condition on this planet, it is probably of lower order. We must, however, not make the mistake of adopting orthodoxically in this respect an attitude that is called geocentricism, which means that everything on the other planets is related to Earth or similar as on Earth. It is up to the first astronaut who sets his foot on Mars to find out whether or not we on Earth have been right or wrong about the things in the surrounding local universe.

THE HUMAN EYE IN THE VISUAL ENVIRONMENT ON THE MOON*

Hubertus Strughold, M.D., Ph.D.

The space medical or bioastronautical problems involved in the establishment of a Lunar International Laboratory are vital for the whole project and are of course numerous. They result essentially from the ecological environmental profile of the Moon and the creation and maintenance of a life-supporting and life-protecting habitat, and of functional equipment. To discuss them only briefly would fill at least one hour. I must, therefore, confine myself to a single specific problem, and I have chosen as the first subject matter for discussion "The Human Eye in the Visual Environment on the Moon" for the following reasons: Vision is the most vital sensory function for perception and spatial orientation in man's life on Earth; this may be even more so in an exotic light environment such as that found on the airless and--according to terrestrial standards--subgravitational Moon. Moreover, the retina of the human eye is an indispensable and irreplaceable sensor in the scientific exploration of the surrounding environment and of the far reaches of the cosmos. In any or all of these respects it is important to analyze in advance the eye's capabilities on the Moon with its exotic photic profile, and to make suggestions to facilitate vision and to provide protection for the eyes, if this should be necessary. Actually we can and must make advance studies of this kind prior to a lunar scientific expedition in order to make it a success.

The light conditions in any environment are determined by the light sources and the photophysical properties of the environment itself. The light sources on the Moon are the same as on the Earth, the only difference being that the Moon as a light-reflecting body is replaced by the Earth. With regard to the optical properties of the environment, the photic conditions on the airless Moon, or the visual scenery as observed on the Moon, or from the Moon, are similar to that in the vacuum of space, i.e., there is no scattering of light, and therefore we have a permanently black sky despite a bright shining sun. Against this black background the stars are just as visible during the lunar day as during the lunar night for the dark-adapted eye. They will appear about 30% brighter and do not twinkle because there is no interference by atmospheric absorption or turbulence. Airglow, which gives the night sky on Earth a slightly bluish luminosity, is of course absent in the lunar sky.

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*Discussion remark prepared for the Meeting of the LIL Committee of the International Academy of Astronautics, Washington, D.C., 2-5 Oct 1961.

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Unlike the Earth and Mars which have their own specific, local terrestrial or Martian sky, respectively, the Moon has nothing else than a plain space sky the same as observed from a space vehicle.

The size of the Sun, the dominant light source, appears to an observer on the Moon practically the same as seen from Earth, namely, 31 min of arc. Its color is more bluish than that seen on Earth and is always--at any position--the same, because no blue rays are scattered out by an atmospheric medium. Because of the absence of a light-reflecting and -scattering medium, the Sun shines, without an aureole, as a luminous disk on a black background. The Sun's corona, consisting essentially of electrons and protons, scatters some light emitted from the photosphere amounting totally to one-half of the brightness of the full Moon (as seen from Earth). But against the brilliance of the solar disk, this will not be perceptible to the human eye.

The illuminance from the Sun is almost the same as that at the top of the Earth's atmosphere, namely 140,000 lux (i.e., lumens per m^2). For comparison, on the Earth's surface, solar illuminance is maximally a little over 100,000 lux. On the Moon, full solar illuminance is immediately observed as soon as the Sun rises over the horizon.

The low-field brightness or blackness of the lunar sky combined with an intensive direct sunlight represents physiologically a strange optical situation, approximated on Earth only under artificial conditions such as theatrical stage lighting. Everything that is exposed to sunlight appears bright with variations, of course, depending upon the reflecting power of the material; everything in the shadow appears dark for a bright-adapted eye. Light and shadow dominate the scenery. This photoscotic condition poses problems in the field of contrast vision and requires special attention in human engineering of the laboratory windows, or of transparent ceilings which should have light-scattering properties. When a selenonaut or scientist leaves the tightly sealed laboratory to study the lunar surface, he should wear on his helmet a light-scattering visor, serving as a kind of blue sky simulator to weaken and diffuse the Sun's concentrated rays and to produce skylight conditions to which he had been accustomed under the blue dome of the terrestrial atmosphere. The sunlit terrain on the Moon probably will not appear brighter than the landscape on Earth because of the low lunar albedo (7%).

The light situation in the lunar craters, of course, is also of interest, because they might be selected as sites for the Laboratory. There might be a great variety of light effects as the result of shadows and solar illumination from opposite sunlit crater rims, which actually is moonlight on the Moon.

Looking directly into the Sun is hazardous because this can cause a thermal coagulation of the retinal tissue, or a retinal burn of various degrees of the kind observed after atomic flashes, or, as often described in the ophthalmological literature under the name "eclipse blindness" (scotoma helieclipticum), that can be acquired if a solar eclipse is observed with an insufficiently smoked glass. Less than 10-sec exposure time may be sufficient to produce such a retinal injury. In milder cases it may be a retinitis solaris which may last for several days. Precaution in this respect, therefore, is indicated, and protection of the eyes is required by means of automatically functioning light- and heat-absorbing glasses, consisting of photoreactive material, reminding us somewhat of the color changes of the skin of a chameleon.

The day-night cycle on the Moon is of 27 days duration. That means the terrain on the Moon is flooded with sunlight one-half of this time.

But we must also consider the earthshine on the Moon. The Earth appears about 3 times as large in diameter as the Sun or as the Moon appears to us on Earth. Its reflected sunlight is essentially bluish in color. This has been concluded from spectrographic studies of the earthlight on the Moon. A certain area of the Earth will also show the moonlight on the Earth. The earthshine on the Moon at full Earth may provide an illuminance value up to some 20 lux. This is about the same as solar illuminance of twice the distance of Pluto or 100 times higher than the lunar illuminance on Earth at full moon, which is about 0.25 lux. Such an illumination goes far beyond the threshold for reading and color discrimination. Thus, the earthshine may be a welcomed, useful component in the photic environment for a terrestrial visitor on the Moon.

The photic environment on the Moon, or more specifically, solar illuminance, is biologically important in another respect, namely, with regard to photosynthetic regeneration of the intralaboratory environment. My brief report, however, is confined to vision on the Moon, or lunar physiological optics, an important line of research inside and outside a lunar research laboratory. So far, this can be merely a physiological evaluation of the astrophysical data until man sets foot on the Moon and looks for himself in situ. But he will find that certain predictions may have been useful for him in preparing certain physiological provisions such as eye protection well in advance.

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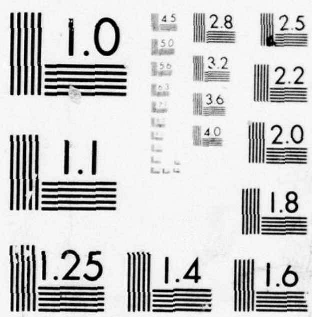

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MARTIAN ENVIRONMENTAL MEDICINE*

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Definition. Medicine is the science and art of preserving and restoring health, well-being, and efficiency of man. If emphasis is directed to the influence of man's physical environment, we speak of environmental medicine, or more specifically, terrestrial environmental medicine. With the appearance of the airplane, aviation medicine, or aeromedicine, came into existence as an environmental branch. With the development of rocketry, aeromedicine was extended into space medicine (1). With the Moon as the first astronautical target, now in the planning phase, lunar environmental medicine is taking shape (2). And, with Mars as the first postlunar target for a manned planetary expedition, Martian environmental medicine appears on the scientific horizon. All of these medical branches, terrestrial and extraterrestrial, can be regarded as subdivisions of an all-embracing cosmic medicine.

Of course, all of these medical branches are anthropocentric oriented because their evaluations of the environments, wherever they are, refer to the ecophysiological requirements of man--*Homo sapiens terrestris*, an oxygen-breathing, homeothermic creature, physiologically adapted to a sleep and activity cycle of 24 hours, and conditioned to the gravitation force of 1 g. His metabolic processes are regulated so as to keep the interior milieu (body fluids) in any exterior milieu almost constant, a tendency called "homeostasis" (3). Proper homeostatic control, which is the function of the autonomic nervous system, is a precondition for man's intact sensomotoric and intellectual activities. If one of the physical or chemical components of the environmental milieu deviates from the normal but is still below the ecological maximum or above the acceptable minimum, the human body reacts with effective compensatory or defensive responses. Beyond these ecological "cardinal points," the psychophysiological functions deteriorate.

In Martian environmental medicine we deal with a very demanding high-level homeostatic terrestrial creature on the one hand, and with an extraterrestrial celestial body with a very-low-level ecological environment on the other. It is then the task of Martian medicine to

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analyze this environment in terms of human physiology and propose to the engineer the necessary life-supporting and protecting systems. It also includes the telemetric or on-board medical control of the health, well-being, and performance efficiency of the areonauts on the way to, during, and returning from a visit to Mars. The accent, of course, lies on the environment encountered on the planet itself, but there are important ecophysiological interplanetary flight and planetary milieu interrelations. Thus, Mars medicine begins and ends on Earth, covering the entire manned Martian-landing mission.

A medical evaluation of the Martian environment can now include the exploratory experiments and closeup photographs of Mariner IV; and, concerning the physiological spaceflight effects, we can make cautious extrapolations from manned-flight durations of 2 weeks (4, 5).

Interplanetary Flight. In this respect, the Gemini record flights of 1965 indicate that under comfortable ecophysiological intracabin conditions and with an appropriate exercise and sleep regimen, man can probably endure spaceflight in the order of months without applying artificial gravity. Nevertheless, it is medically advisable to base the flight plan to Mars on a high-energy trajectory to shorten the duration of the minimum-energy trajectory of about 8 months to 30% or 20% of this time, which might be achieved by novel methods of propulsion.

There are various reasons for this, resulting from the man-machine-environment complex: logistic reasons concerning power supply and life support, physiologic and psychologic, and finally external space-environmental reasons. With regard to the latter, a short time reduces the possibility of collision with meteoroids (with puncture capability) and the radiation hazards of an encounter with solar flares. In brief, minimum time and optimum comfort during the interplanetary flight should be the medical prescription in order to achieve maximum success of the planetary-landing mission. Particularly with regard to the psychophysiological aspects, the astronauts with week-long experiences in circumterrestrial orbital flight and the physicians who have controlled these flights must have a decisive voice. The onboard experimental studies concerning blood volume, dehydration, vascular tone, and mineral metabolism of the bones, carried out so far (6) and those planned in the future, should give us a final answer. After these brief medical remarks concerning interplanetary spaceflight, we now take a medical look at the environmental profile of Mars itself.

Parking Orbit. As soon as a Mars ship comes closer than 1/2 million km to the Red Planet, it enters its sphere of predominant gravitational attraction (inner gravisphere (7) or satellitesphere), and can go into a parking orbit for observational tasks or preparing for the landing maneuver. But out to several times this distance, the gravitational attraction of Mars gradually becomes noticeable in the vehicle's trajectory and velocity, as was actually observed on Mariner IV. I'd like to point out, also, that the Mars shadow, or umbra, extends to 1.18 million km.

Fortunately, there are no radiation hazards from a Van Allen-type radiation belt in circum-Martian space; the magnetometers and radiometers on board Mariner IV recorded the absence of an effective magnetosphere and, consequently, no concentration of particle rays of any radiobiological significance (8). Therefore, no regions are "off limits" for parking orbits, in contrast to the situation in circumterrestrial space. Table 1 shows the orbital periods and velocities at selected altitudes up to 20,000 km. It also includes the mean orbital elements of the two Martian moons, Phobos and Deimos.

TABLE 1. ORBITAL CHARACTERISTICS OF ARTIFICIAL MARS SATELLITES*

Altitude (km)	Period of revolution (hr)	(min)	Orbital velocity (km/sec)
0	1	40	3.56
100	1	45	3.51
200	1	49	3.46
300	1	54	3.41
400	1	58	3.36
500	2	01	3.32
600	2	08	3.28
1,000	2	27	3.13
2,000	3	20	2.82
4,000	5	22	2.41
5,980 (Phobos)	7	39	2.14
8,000	10	15	1.94
10,000	13	03	1.79
15,000	21	01	1.53
20,100 (Deimos)	30	18	1.35

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The question arises "at what altitude lies the lower limit for a useful lifetime of an orbiting vehicle?" For Earth this level is found at about 200 km. As the radio-occultation experiment in Mariner IV indicates, the surface air pressure on Mars might be as low as 10 to 5 mbar (9); but because of the lower Martian gravity and temperature conditions in its upper atmosphere, the border of the effective or sensible atmosphere might extend just as far as on Earth. A parking orbit of 200 km would certainly provide a revealing perspective for visual observation and for Mars photography, in a kind of Orbiting Martian Observatory

(OMO). The orbital velocity at this altitude is 3.46 km/sec, or about half of that at the same height in circumterrestrial space. From this altitude the resolving power of the unaided human eye is about 60 m (minimum separable). This would enable the observer to get a panoramic view of the dark linear markings (canali) and to clarify the question whether the bluish-green coloration of the dark areas and oases is real or a visual contrast phenomenon against the reddish surroundings. All indications are that the green color, of the larger areas at least, is not an optical illusion; and about those Earth-based telescopic observers who insisted that these areas always looked gray, the orbiting areonauts might wonder if they had ever had their color vision examined. From their altitude the orbiting areonauts would probably not be able to determine what causes the green coloration, vegetation or reaction of the soil chemicals to variations in humidity or to fluctuations in radiation. To find this out would require landing and exploring the surface itself.

Gravitational Milieu on Mars. With the beginning of deceleration during the landing maneuver, whatever method is used in the thin Martian atmosphere, gravity again enters the life of the areonauts who, after a long interplanetary weightless journey, have become completely deconditioned from gravity. If during this travel time an adequate exercise regimen has been applied, they should have no serious cardiovascular problems in becoming conditioned to the Martian gravity, 0.38 g; certainly, this should be easier than the reconditioning upon return to Earth from Mars.

In manned orbital flights the astronauts showed a slightly lowered blood pressure. This has been interpreted that, during weightlessness, the parasympathetic subdivision of the autonomic nervous system has become somewhat dominant over the sympathetic part. If this is so, then we might expect to some degree also a parasympathicotonia (vagotonia) in the gravitational milieu on Mars.

Furthermore, the hydrostatic blood pressure pattern might show a smaller difference between the lower and upper part of the human body in the upright position on Mars as compared to on Earth (10). All of this should have no consequence for the health of the areonauts.

A man of 75-kg mass on Earth has 75-kg weight, or 75 kiloponds (from Latin: pondus=weight, a relatively new but already widely used unit in physics); on Mars, a man with 75-kg mass has a weight of 26 kiloponds. This should provide sufficient stimulus to the otoliths and the peripheral mechanoreceptors in the skin and muscles for their sensomotoric control of walking on the Martian surface; it certainly should be easier than on the Moon, where as lunar-gravity simulation experiments indicate, walking might require some caution. Also, because of the lower Martian gravity, the use of a single-man propulsion unit to carry the areonaut through the air would be much more efficient on Mars than on Earth.

In brief, biodynamics on Mars should pose no particular problems; in fact, in this respect life for terrestrials might be easier there. From the medical knowledge we have gained from manned orbital spaceflight, it might be justified to expect for the areonauts, after a few days, a "relatively stable adaptation" to Mars' gravity.

Environment Outside and Inside the Mars Station. Human metabolism in its energy-production phase (catabolic phase) is based on oxidation. Under Earth's gravitational standard of 1 g, we can assume for a man of about 75 kg--under normal nutrition, light workload, and some exercise--a metabolic rate of 2500 kcal per 24 hours.

Under the weightless condition during their orbital flight, the daily metabolic rate of the American and Russian astronauts varied from 2100 to 2400 (11). Using these gravitational baselines (1 g and zero g), it seems reasonable to assume a caloric requirement of 2400 kcal on Mars. This metabolic rate requires roughly 500 liters of oxygen per areonaut per Martian day, which is only 37 minutes longer than that of the terrestrial day.

The natural oxygen source of man as a lung-breathing creature is Earth's atmosphere, with 160 mm Hg (210 mbar) oxygen partial pressure. On Mars, environmental medicine faces the following situation in this respect: The chemical composition of the Martian atmosphere includes carbon dioxide, nitrogen, argon, and only traces of oxygen, if any (11, 12). This means it is not an "atmosphere" in its literal sense; i.e., breathable air. Exposed to this kind of gaseous sphere, terrestrials would experience complete oxygen lack (anoxia). Furthermore, if the surface air pressure is in the range of 10 to 5 mbar, as indicated by Mariner IV, this would be barometrically equivalent to an altitude of 30 to 35 km on Earth and, consequently, would cause boiling of the body fluids, or ebullism, which in our atmosphere occurs at 20 km (Armstrong line). The "time of useful consciousness" (or "time reserve") of a man suddenly and completely exposed to the Martian air would be less than 1 minute.

Thus, an adequate atmospheric environment for terrestrial visitors must be artificially provided in a closed ecological system, similar to the one in which they arrived on Mars. The question arises "what barometric pressure and chemical composition should this artificial atmosphere have?" With regard to chemical composition, we could choose pure oxygen at a reduced pressure or a two-gas atmosphere--with either nitrogen, helium, or neon as a diluent.

Pure oxygen at a pressure of 260 mm Hg (345 mbar) has proven to be adequate in manned orbital flight in the order of 2 weeks. In extended flight in the order of months, however, a two-gas atmosphere seems to be desirable. Experiments of 1-month duration in spacecabin simulators have shown that helium can be used instead of nitrogen (13). The natural choice concerning a two-gas atmosphere, however, still is oxygen and nitrogen. If a barometric pressure of one-half of 1 atmosphere (500 mbar) is chosen, the oxygen volume content should be 40%, providing an O_2 partial pressure of 160 mm Hg (210 mbar), to which the areonauts have been accustomed on Earth. Nevertheless, variations in the O_2 partial pressures of ± 50 mm Hg are within the permissible limits.

The material end-products in the body's oxidation processes are carbon dioxide and water. This so-called metabolic water amounts to 10% of the actual daily water intake of about 2 liters (14). Thus, man eliminates more water than he drinks, which is logistically of some interest. The carbon dioxide within the living quarters should not exceed 0.16 mm Hg (0.2 mbar). Both carbon dioxide and water are the base material for the biologic (i.e., photosynthetic) regeneration of oxygen of the station's air. Whether or not the carbon dioxide and nitrogen of the surrounding thin Martian air can be made available for this process is a bioengineering problem. (Nitrogen, by the way, is required by plants for the buildup of protein.) The intensity of sunlight on Mars during most of the day is within the effective range required for photosynthesis (see below). I cannot go into the bioengineering details of the life-supporting system in which basically the life-supporting properties of Earth's atmosphere and the oxygen regeneration by green vegetation are reproduced. I would like to add only that the pressure suit used in extrastational excursions should have an oxygen pressure of around 180 mm Hg (240 mbar).

The Mars station must also protect the occupants from outside hostile factors such as the arcticlike low temperatures during the night, particle radiation, and meteoritic impacts.

On Earth we are protected from some of the primary energetic particle rays by the trapping and deflecting effect of the magnetosphere; and those which reach the atmosphere are transformed in collisions with the air molecules into less powerful secondary and tertiary rays, to which we are daily exposed without ill effects. On Mars, without such a magnetospheric umbrella, the particle rays in their primary form reach unhindered the atmosphere. But with a surface density in the order of 10^{17} molecules/cm^3, as compared with 10^{19} molecules/cm^3 in the terrestrial atmosphere, the Martian air offers only a partially effective shield in this respect. It will be essentially a function of the wall of the Mars station to absorb the primary particle rays effectively, or at least to keep the radiation dose at a level which the astronauts have absorbed during their orbital flights, which was less than 1 mrad/hour. This should be no difficult bioengineering problem. The pressure suits worn outside the station must offer sufficient protection for a few hours' excursion; but should Mars be hit by a proton outburst after a solar flare, extrastationary activities (E.S.A.) would be prohibited.

The low density of the Martian atmosphere, as indicated by Mariner IV, brings the possibility of meteoritic hazards into the discussion, particularly since the situation in this respect is influenced by the neighborhood of the belt of asteroids. It has been theorized that some 300 million years ago a planet X between Mars and Jupiter disintegrated into many thousands of asteroids, forming the asteroid belt. It is reasonable to assume that this catastrophic event, or a collision of two smaller planets, led also to a population explosion of smaller pieces of matter--macro- or micrometeoroids. These iron and stony-iron meteorites found on Earth are probably of asteroid origin. Mars is much closer to the asteroid belt and should attract considerably more of these "bullets from space." Two characteristics might moderate their puncture potential: a) their velocity is similar to Mars' orbital velocity and lower than at Earth's orbital region, and b) they might orbit essentially in the same direction as Mars, so that hits on Mars should be essentially rear-end collisions and not head-on collisions. Nevertheless, the wall of the station, as of the spaceship, must include a meteor bumper structure, as suggested by F. Whipple (15). Micrometeorites might to some extent be absorbed by the Martian atmosphere itself.

Meteoroids of cometary origin consisting of ice and dust (Whipple) also might pose no hazards when we consider that even in open circumterrestrial space, so far, no meteoritic interference--even during extravehicular activities--has been observed. But we need more astronomical information about the impact rate on the Martian frontside and rearside and, furthermore, on Mars' penetration dates of meteor streams.

All in all, the artificial atmosphere inside the Mars station has to be in its very nature a terrestrial environment for life support and its wall has to serve as a protecting shield from outside factors, similarly as the terrestrial atmosphere does. A Mars station, therefore, is actually an Earth station on Mars--a "Terra-Island on the Red Planet."

<u>Location of Mars Station</u>. Where should this station be located, or in what region should the areonauts land? Environmental considerations suggest the dark areas in the lower latitude regions in which springtime has just begun. This offers for the spring and summer season, lasting more than 300 days, a relatively mild climate during the daytime. Illuminance at noon at ground level may attain an intensity of 40,000 lux (lumens/m^2), adequate for the photosynthetic regeneration system, and thermal irradiance may reach up to 0.6 cal/($cm^2 \cdot$min), which facilitates especially extrastational excursions. From the point of view of thermoecology of the landing place, it might not be too farfetched to look on the Martian surface for warm spots of a kind as they exist on Earth; for instance, on Mt. Wrangell, Alaska, where the Aerospace Medical Division, Brooks AFB, Texas, in 1964 constructed a laboratory on a perennially warm, snow-free, volcanic sand surrounded by snow and glaciers, 4211 m high (F. Holmstrom - 16). This installation does not require any heating at any time. It utilizes thermal output of an inactive volcano. Knowledge in advance of similar permawarm spots on Mars might be obtained by scanning its surface by means of infrared or far-infrared sensors from the OMO mentioned earlier.

So far I have not mentioned the material resources for the Mars station possibly obtainable from the lithospheric surface. Data in this respect are offered in reference 17. I would like to mention only a hypothesis concerning the possible existence of a water source in the form of an ice layer some 100 m below the lithospheric surface (18, 19, 20a). It is logical to assume that this hydrocryosphere (20b), a remnant of the ancient Martian ocean, may be located below the dark areas and oases; below this ice table, some 500 m below the ground, there might even be a water table due to an increase of temperature in the interior of Mars (19). This, again, would point to these areas as the most promising location for the landing place and the establishment of the Martian station.

Finally, if there is a biosphere on Mars, the dark areas with their seasonal color variations are the regions to look for it. After all, the search for life outside the Earth is a supreme goal of any manned planetary expedition (21). For medicine, it poses the problem of preventing contamination of the areonauts with possibly pathogenic Martian microbial organisms.

Exploratory Tasks. There is no question that a manned Mars expedition is the best way to explore the Red (or green and red) Planet as a possible abode of life. A precondition in this respect is that contamination with terrestrial microorganisms has not occurred by insufficiently sterilized unmanned probes prior to the manned expedition; this is the task of preventive medicine (22). An overall synopsis of the pro and con arguments speaks for the possibility or even probability of life on Mars, particularly within its microenvironments found in craters, fissures, and the pores of the soil. Only areonauts during extrastational excursions can take a critical, deep look upon rock formations in craters and fissures, which might give us a hint about the paleontological evolution of the Martian biosphere. They are in the best position to clarify the areographic features such as the dark linear markings (canali) and oases. The latter are in all probability impacts of giant meteorites of asteroidal origin, and the linear markings might be tension cracks resulting from planetary expansion due to a decrease of the gravitational constant (R. H. Dirac, 23) and triggered by these impacts.

If there is a subsurface ice layer, then humidity might be higher in and around the oases and along the fissures, thus making these locations ecologically more favorable for the growth of plantlife. Actually, it might be the soil's humidity and the resulting vegetation that has made these areographic features visible to Earth-based optical astronomy in the first place. Furthermore, if there should be a water table below the subsurface ice layer, then there could be, in addition to the surface biosphere based possibly on some kind of photosynthesis, a subsurface marine habitat for microbial life based perhaps on chemosynthesis. This would be of interest to biology and medicine as well.

All of this is hypothetical, but we cannot ignore any one of these possibilities. It might well be that Mars hides just as many scientifically attractive mysteries below its lithosphere as Venus does below its cloud-veiled atmosphere.

A manned expedition to Mars will be the most dependable method of extending the spectrum of our knowledge about its paleological evolution and biotic realities beyond that range that has been gained so far and that will be explored in the future by Earth-based astronomy (24, 25) and instrumented planetary probes.

To perform all these scientific tasks, the Martian explorer must be kept in the state of best health and well-being--on the highest physical and mental level. To secure this is the responsibility of Mars medicine. And, last but not least, it is its responsibility to control the safe return of the Mars-adapted terrestrials on their way back to their blue home-planet, Earth, and to prevent back contamination of the latter with Martian microorganisms.

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AT THE THRESHOLD OF THE COSMOZOICUM

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One of the primary and most fascinating goals of astronautics is the search for life on other celestial bodies. The branch of biology concerned with this question has several names: astrobiology, cosmobiology, and exobiology. To get some ideas in this area, we must look into the history of life on our own planet.

In geological and biological science the historical development of life on Earth, which may cover some 2.5 or even 3 billion years, is conventionally subdivided into five eras: the Archeozoic era, or Archeozoicum; the Proterozoicum; the Paleozoicum; the Mesozoicum; and the Cenozoicum. These subdivisions, except the first, are largely based on fossil records of life in the rock strata.

The Archeozoicum (from archaios, meaning primeval), began some 2.5 or 3 billion years ago, and is regarded as the era of the origin of life on Earth--the era of the chemical evolution and of the first living creatures, or protobionts. These might have been microorganisms of the subbacterial stage--virus and heterotrophs which can live on prefabricated organic material only. Since we have only very nebulous ideas concerning this era, it is also called the Cryptozoicum (from cryptos, meaning hidden or secret).

The next era is the Proterozoicum (from proteros, early), beginning perhaps some 2 billion years ago. In all probability it was the exclusive era of the unicellulars, or of microorganisms such as bacteria and algae. The algae became very effective agents in the photosynthetic oxygenation of Earth's atmosphere. In this era the ozonosphere must have come into existence, providing a protective shield for Earth's surface against ultraviolet rays.

The Proterozoic era was followed by the Paleozoicum (from palaios, ancient), with the appearance of the multicellulars, which reached their highest stage in the fish family.

In the meantime, the atmosphere had become more and more oxygenated by the photosynthetic activity of green algae and other green plants. This made possible the development of higher animals. The next era, the Mesozoicum (from mesos, middle), started some 300 million years ago. In the animal world it was the time of the dominance of the reptiles and dinosaurs. Plant life had reached a luxuriant level, as manifested in tremendous deposits of coal dating back to this era.

The Cenozoicum (from cainos, recent), with five subdivisions, is the latest chapter in the geobiological history book and includes the development of warm-blooded animals and man, *Homo sapiens terrestris*.

All of these historical subdivisions refer, of course, to life on Earth. They are actually the geoarcheozoicum, the geoproterozoicum, the geopaleozoicum, the geomesozoicum, and the geocenozoicum. But our thinking concerning life is no longer confined to Earth. It includes other planets and the Earth's moon. This actually began in the second half of the last century, especially with Schiaparelli's report of canals on Mars. But the rocket has really given impetus to this trend of thinking because it offers the possibility of studying the existence of extraterrestrial life in situ (on other celestial bodies themselves), via planetary probes equipped with life-detecting devices and by manned space expeditions. In finding out for certain if there is exolife, we must prevent contamination of other celestial bodies via space probes by sterilization of these devices.

When manned flight to one of the neighboring planets has been achieved, however, contamination of the environments by terrestrial microorganisms probably will be unavoidable, and some may flourish there. On the other hand, extraterrestrial microorganisms, if there are any, will certainly be brought to Earth via space vehicles and will be integrated in the terrestrial biotic environment. All in all, as soon as we have definite knowledge of the existence of exolife and when technologically induced interplanetary transmigration has taken place, we will have entered a new biological era which we might call the Cosmozoic era, or the Cosmozoicum.

It must be noted that in contrast to the Cosmozoicum, the terrestrial "zoicums" have a time prefix. They refer to biotic eras on Earth about which we have more or less well-founded knowledge based on geological evidence. The developmental eras pertaining to life on other planets--if there is any--are, in all probability not synchronous with those on Earth. Present life on Mars, or the Martian Cenozoicum, might still be at the stage of the terrestrial Proterozoicum or early Paleozoicum. And if organic compounds and microorganisms should be present in the upper layers of Jupiter's atmosphere, produced by solar ultraviolet radiation, then the Jovian Cenozoicum would be comparable with the terrestrial Archeozoicum. Therefore, the timeless designation "cosmo" might be appropriate. With regard to life on Earth, we are in the Cenozoicum; but considering the whole planetary spectrum of biotic potentialities, we are at the threshold of the Cosmozoicum. To the geological eras of life we might have to add planetological eras, with geobiology and areobiology (for Mars) becoming merely subdivisions of an all-embracing planetary biology, astrobiology, or cosmobiology.

The first "signs" of the advent of this Cosmozoic era are distinctly visible today. It is indicated by the widespread increased discussions in the popular and scientific literature concerning "exolife"; by an increased astronautical interest in the planets, with new methods of astronautical observation such as in radar astronomy; by sending lunar and planetary probes on close fly-by missions such as the Mariner; by the development of life-detecting devices; by studies of terrestrial organisms under simulated extraterrestrial conditions; and last but not least, in new theories of the origin of life and life distribution in the planetary system.

In the following I should like to elaborate on these items in more detail and shall begin with this last problem--the origin of life, which is fundamental in terrestrial and extraterrestrial biologies; and we shall return to the Archeozoicum of Earth.

It has been theorized that some 2.5 billion years ago--in Earth's primary atmosphere containing hydrogen, ammonia, methane, and water vapor, organic compounds such as amino acids were produced by solar ultraviolet radiation and settled down in the oceans, turning them into a kind of organic nutritional "soup" (H. Urey, Haldane, Oparin). This process could also have taken place in the surface layers of the waters because, during the preozonic time, solar ultraviolet could pass unhindered through the atmosphere. Lightning, too, has been considered as a possible agent. This abiogenically produced organic material is considered to be the prestage for the origin of life, which might have appeared first in the form of heterotrophs. That such photochemical or electrochemical reactions occur, was verified in 1954 by means of a silent electrical discharge in a chamber containing the gas composition of the primordial atmosphere (Stanley Miller). Later this experiment, with ultraviolet rays and heat, was successfully repeated in other laboratories.

It also appears plausible to assume that the particle rays, the flux of which is influenced by the geomagnetic field, may have played a role in the origin of life. They are channeled into the polar regions; some are trapped, forming the Van Allen radiation belt. The horns of the outer radiation belt dip considerably into the atmosphere in the subarctic latitudes. Both of these ray particles, channeled and trapped, are responsible for the polar lights and for increased temperatures, particularly after solar flares. These polar regions may have been especially effective locations for the production of prebiotic material. Exposure of protoatmospheric gaseous matter to particle rays in the laboratory have led to the production of organic matter. It could even be tested in situ; i.e., in the Van Allen belt itself via satellites carrying a container filled with ammonia, methane, and water vapor. This, then, would be a small-scale recapitulation of the gigantic paleontologic event that might have taken place in archaic times on Earth, in the contact zones between its primordial atmosphere or ancient oceans, and the radiation energies emitted from the Sun.

This abiogenic production of organic material by ultraviolet and, perhaps, particle rays, represents the phase of "chemical evolution" as the prestage for the origin of life during the Archeozoicum. After the appearance of the first microorganisms, which we consider to have been heterotrophs, the phase of evolution of metabolic systems (chemoautotrophs, photoautotrophs) followed. This phase, during the Proterozoicum, was followed by the evolution of morphological systems in the Paleozoicum and, finally, by the phase of sensomotoric and sensoric systems.

This is, in brief, a survey of the origin and development of life on Earth. It is assumed that a similar origin and evolution of life might have taken place on other planets, if the chemical and radiation conditions were adequate.

CELSIUS IN--FAHRENHEIT OUT

Hubertus Strughold, M.D., Ph.D.

In measuring the temperatures, "Celsius" is on the way in, and "Fahrenheit" is on the way out in the United States. This is a sound and reasonable development which is better understood if we look into the past history of these two scales of measurements.

In 1714, Gabriel Daniel Fahrenheit (1686-1736), physicist in Danzig, Germany, invented the mercury-in-glass thermometer. This was a milestone in thermometry.

Fahrenheit needed a zero point and 100 point on the temperature scale. During a Siberian cold front that hit the area of Danzig, the weather was so cold that he thought it could never be any colder, so he chose this lowest temperature for the zero point. Then Fahrenheit needed a second stable point, and he thought the temperature of the human body is rather constant, but when he discussed this idea with the doctors at the city hospital in Danzig, they told him that patients with pneumonia or an inflammation had a higher temperature. The doctors gave Fahrenheit permission to measure the temperatures of 12 patients during the next few days. He did this and took the average of their temperatures as 100 degrees. These two points are the basics on the Fahrenheit scale.

Some years later, Anders Celsius (1701-1744), astronomer in Uppsala, Sweden, used a different scale. He used the freezing point of water as zero and the boiling point of water as 100.

This is a simple physical basis and understandable by everybody. When Fahrenheit later heard of the Celsius scale, he liked it better; and he did not like it that the freezing point of water was 32° Fahrenheit and the boiling point 212° Fahrenheit.

In summary, the Celsius scale is based on the freezing point and the boiling point of water. The Fahrenheit scale is based on one of the coldest nights in Danzig in 1714, and on the average temperature of 12 patients in the city hospital at Danzig in 1714. This comparison makes it perfectly clear which method will be the one of the future--<u>Celsius</u>!

But we must always remember Fahrenheit was the inventor of the mercury thermometer, which has been and still is of great benefit for technology, natural sciences, and medicine.

COSMIC SLEEP

Hubertus Strughold, M.D., Ph.D.

Sleep is a vital and usually pleasant factor in human life. Though its cause and nature are not yet completely understood, a regular sound sleep is recognized as a precondition for man's health and his intellectual and general life activities during the state of wakefulness. Both wakefulness and sleep form a continuously recurring physiological cycle, which is closely related to the physical cycle of day and night, or light and darkness, caused by the Earth's axial rotation in the powerful electromagnetic radiation field of the Sun, resulting in periodic changes in illumination, temperature, and other environmental properties. Because of this close association, the sleep and wakefulness cycle is called the "physiological day-night cycle," or the "circadian cycle" (derived from circa and dies, which means around one day (Fr. Halbach)).

Depending on the sensitivity of the eyes (retina) and other orientation senses, the activities of man and most of the animals take place during the day. They are "light active," whereas nocturnal animals such as bats and owls are "dark active." The "zeitgeber" (J. Aschoff), or time cue for sleep and activity, is the disappearance and reappearance of solar illuminance at sunset and sunrise.

Such is the general picture of the sleep and wakefulness cycle under normal natural environmental conditions on the Earth's surface, with its 24-hour-long day-night cycle. In contrast, an orbiting spaceship in nearby space is not fixed to the rotational regime of the Earth; it revolves around it in fractions of the terrestrial day-night cycle. It is therefore of greatest interest to study the possible sleep-wakefulness pattern of astronauts. This study is medically important because without a sound sleep regulation there cannot be a successful extended manned space operation.

Before we start to discuss this matter we should first briefly review the fundamentals of the physiological circadian cycle by looking behind the visible scene of the phases of sleep and wakefulness.

Beginning with the highest organized organ--the brain--the electroencephalogram shows a decrease of the 10 cycles per second alpha waves down to 3 or 2 during sleep. Telemetry offers a convenient and precise way of recording the sleeping time of astronauts. During sleep there is a considerable relaxation in tonus of the skeletal muscles that indicates a lower metabolic rate, which is reflected in a slowing down of the respiration and heart rate during the night. In contrast, activity of the intestinal tract is increased during this time, and there are also circadian maxima and minima in the functions of the kidneys and the endocrine glands. Generally, the sympathetic division of the autonomic nervous system predominates during the day and the parasympathetic division, during the night.

It is, of course, not surprising that the blood, as a kind of mirror, reflects the picture of the overall activities of the body in the form of day-night variations in its chemical and morphological constituents.

All of these variations on an organ-, cellular-, and molecular-level, harmoniously integrated into a functional circadian system, with the thalamus of the forebrain as the coordinating center, repeat themselves with clocklike regularity within the temporal frame of 24 hours, so that the cycle researchers speak of a "metabolic clock" or a "physiological clock." An easily recognizable indicator of this physiological clock is the body's temperature, with a maximum in the late afternoon and a minimum in the early morning.

In man, as in numerous animal species, the circadian cycle is firmly established as a vital endogenous feature. The normal physiological time requirement for sleep, or the normal sleep dosage, is 8 hours within 24 hours, as derived from observations of people who are not under community, social, and professional pressure. To break this cycle completely by staying awake for several days leads to neurotic disturbances. From history it is known that Napoleon I, Emperor of France, and Frederick the Great, King of Prussia, tried to demonstrate that sleep is just a bad habit. After two nights without sleep they had to capitulate to the more powerful Morpheus--god of sleep and dreams.

A certain stability of the sleep and wakefulness cycle is also proven by the fact that a time shift cannot be achieved instantly; rather, it requires a certain amount of time for readjustment. This is a familiar problem in work shifts in factories, mines, hospitals, on ship watches, and in astronomical observatories. In these cases the individual changes the time of his activities but stays in his home time zone. With the development of fast-moving surface vehicles, and especially since the advent of the airplane, a phase shift of the day-night cycle takes place by a change of the time zone (Juin, 1963; Marti-Ibanez, 1956; Strughold, 1952, 1962).

The geographic time difference is 4 minutes per one meridian, or 1 hour (one time zone) per fifteen meridians, making a total of twenty-four time zones.

Within the higher range of the first aeronautical speed (subsonic speed) and with the second aeronautical speed (supersonic speed) a half dozen time zones can be crossed within a few hours. In this way, a traveler is exposed in a matter of hours to a physical day-night cycle different in time from that at the point of departure and, consequently, different from the physiological day-night cycle still in his system. This results in a phase shift between these two cycles, or what is called "desynchronization" in biorhythmology, and it takes several days to 1 week until the traveler is adapted to the local time of the terminus of the trip, or until the two cycles--physical and physiological--are resynchronized.

As statistical observations in long-distance flights have shown, the majority of people--especially older people--are sensitive to this phase shift, and experience some physiological discomfort. They become hungry, get sleepy, or are awake at the wrong time. Some people are not particularly sensitive in this respect and can sleep like a cat at anytime, at any place, and under any circumstances.

If we wish to use a name for the physiological or psychophysiological effect of cycle desynchronization, in medical terminology, "desynchronosis" would be a suitable designation, and the individual can be considered as "desynchronotic." However, it should be emphasized that this transient condition is not a disease; it is merely a phase shift between the temporal physiological requirements of the body and the local physical situation and professional and social requirements at the new place; but this can be significant professionally and medically.

With space flight or astronautics we deal with a completely novel situation. The customary geographic day-night cycle is replaced by an erratic sunlight-Earth shadow cycle. In orbital spaceflight man finds himself in a vehicle which has the motion characteristics of a celestial body--that of a planetary satellite. Within the relative radiation-safe altitude range from 200 to 800 km below the Van Allen radiation belt, the orbital period lasts from 80 to 130 minutes. Maximally, about 30% of this time--depending upon the orbit's inclination--is satellite night, or Earth-Shadow Time. This means that the external photoscopic cycle in orbital flight in Earth near space is never longer than one-tenth of the day-night cycle on Earth.

In interplanetary spaceflight beyond the Earth's gravisphere (1.5 million km), which requires the second astronautical velocity or escape velocity (11.2 km/sec), astronauts are beyond the reach of the Earth's full shadow or umbra, which ends at a distance of 1.3 million km. Here is constant sunshine and a velvet black sky, or, so to speak, day and night at the same time.

But in this unearthly environment of near and deep space, with short contrast-rich photic periodicities, or with no photic periodicities at all, the astronaut still is bound to a temporal pattern of sleep, rest, and activity, which he inherited from his life on Earth, with its regular, circadian cycle. The behavior of his physiological clock is still basically dictated by his physiological nature as a terrestrial creature with millions of generations of ancestry!

Let us first review what was actually experienced by the men who have been longer than 24 hours in Earth's near space.

Astronaut Gordon Cooper (22 orbits, 34 hr 20 min, 1963) found that even early in flight, when he had no tasks to perform and the spacecraft was oriented so that the Earth was not in view from the window, he easily dozed off for brief naps. During the period designated for sleep he slept only in a series of naps lasting no more than 1 hour each. His total sleep time was about 4.5 hours. He stated that if there had been another person along to monitor the systems he could have slept for much longer periods. He further stated that he slept perhaps a little more soundly than on Earth (Catterson et al., 1963). The long period of alertness, of course, enabled Cooper to utilize his orbital time to the optimum for his operational and exploratory tasks.

Also, the first "cosmic slumber" of the second Russian cosmonaut, Gherman Titov (17 orbits, 25 hr 18 min, 1961), was not without interruptions. After 7 orbits he felt a definite state of fatigue. When he flew over Moscow at 6:15 p.m., he prepared for sleep, according to schedule, by releasing special belts from the side of the pilot's seat strapping his body to the contour seat, and adjusting the seat to the bed position. He promptly fell asleep, but awakened much earlier than scheduled. This happened during the 8th orbit. When he opened his eyes he saw his arms dangling weightlessly and his hands floating in mid-air. "The sight was incredible," Titov reports. "I pulled my arms down and folded them across my chest. Everything was fine--until I relaxed. My arms floated away from me again as quickly as the conscious pressure of my muscles relaxed and I passed into sleep. Two or three attempts at sleep in this manner proved fruitless. Finally I tucked my arms beneath a belt. In seconds I was again sound asleep." Titov further states: "Once you have your arms and legs arranged properly, space sleep is fine. There is no need to turn over from time to time as a man normally does in his own bed. Because of the condition of weightlessness there is no pressure on the body; nothing goes numb. It is marvelous; the body is astoundingly light and buoyant....I slept like a baby." (Titov et al., 1962).

He awoke at 2:37 a.m., Moscow time, and was a full 30 minutes behind schedule because of oversleeping. He immediately started the required "morning calisthenics." Thereafter he carried out all scheduled assignments, and during the 17th orbit prepared the rocket and himself for the "baptism of fire"--atmospheric reentry. It is of interest to note that Titov's sleeping period coincided largely with nighttime over Russia. This also was true of the other Russian cosmonauts.

Valery Bykovsky (81 orbits, 119 hr, 1963) slept four times for periods of 8 hours, alternating with periods of 16 hours of wakefulness (Parin et al., 1964). During the latter's flight and that of

Valentina Tereshkova (47 orbits, 71 hr, 1963) "the diurnal periodicity of physiological functions changed only during the first and last days of the weightless state, which was most probably associated with the emotional strain." During the phases of wakefulness, brief rest periods were usually scheduled for times when the spaceship was not over the Soviet Union. "It should also be noted that at night, during sleep, nearly all cosmonauts displayed a greater reduction in pulse rate than that recorded during the same hours in earlier space simulated flights." (Gazenko, 1964).

The three-man team of the spaceship Voskhod (16 orbits, 24 hr 17 min, 1964) rested and slept in shifts during their 24-hour flight.

In summary, the reported sleep and wakefulness time patterns in spaceflight reflect, by and large, the physiological circadian cycle. But, except for some operational reasons, this cycle does not necessarily need to be synchronized with any place on Earth. For the astronauts, the geographic time zones are physiologically meaningless. They are in a state of asynchrony with regard to these Earth-surface temporal zones. Especially in extended (geocentric and heliocentric) spaceflights, the astronauts probably will follow a physiological sleep and wakefulness cycle adjusted to their duties, independent of the ambient exotic photic space environment, and not necessarily completely corresponding to the temporal pattern of their physiological circadian cycle on Earth. It might be what is called in the science of biorhythmology, a "free-running cycle" (Brown, 1959) that certainly will include a sleep period of 5 to 8 hours every 24 hours. Five hours of sleep with occasional catnaps every 24 hours has been found very adequate in space cabin simulator experiments lasting several weeks (B. Welch). In earlier experiments, a 4-hour sleep--4-hour activity cycle, as is customary in submarines, and other patterns have been tested, and might be adequate for short durations but not flexible enough for extended space operations. According to early experiments in caves, the length of the whole circadian cycle can be shortened and prolonged to a certain degree. The temperature curve, for instance, adjusts itself to approximately a 24-hour day (Kleitman, 1939).

It is encouraging to learn from the aforementioned space reports that space sleep poses no difficulties. This is a precondition for the maintenance of high performance capability of the astronauts and for their health. Furthermore, exercise is necessary to prevent certain observed physiological disturbances such as orthostatic hypotonia of the muscles and veins and will automatically contribute to the establishment of a sound pattern of sleep and wakefulness. In the case of a multicrew flight, a prelaunch, preadaptation to the programmed space pattern, with different shifts of sleep, rest, and activity for the various crewmembers, will certainly be helpful to precondition them for an efficient sleep-activity regime in a space station. And last, but not least, the intra-cabin radio noise must be kept below the sleep-disturbance level as has been emphasized by Astronaut McDivitt.

On the Moon, the physiological sleep and activity cycle will be completely independent of the physical or selenographic day-night cycle, which is 27 terrestrial days in length. In addition to sunshine, with an illuminance of 140,000 lux (lumens per square meter), the earthshine at full Earth, with an illuminance 75 times stronger than that of the moonshine on Earth at full Moon, provides a photic situation approaching a dim-daylight situation on Earth. Furthermore, there may be locations with no effective illumination at all (crater), or places with constant sunlight as on the "mountains of eternal light" near the South Pole.

Be that as it may, the photic environment on the Moon does not provide a "Zeitgeber" comparable to the 24-hour dark-light cycle on Earth. Therefore, the selenonauts might adopt a sleep and activity cycle of the terrestrial circadian pattern, modified by their special tasks and by the lower gravity on the Moon.

On the most attractive postlunar astronautical target--the red planet Mars--the day-night cycle is only 37 minutes longer than that on Earth. The sky is dark bluish in color, except in regions covered with thin whitish clouds. Solar illuminance on the Martian surface at noon may reach one-third of that on Earth. Thus, the temporal dark-light alternation on Mars offers a day-night time cue familiar to terrestrial visitors for their physiological sleep-activity cycle, and, consequently, there should be no difficulties in this respect in a Martian station.

If there should be indigenous or native life in the dark blue-green surface regions on Mars, in the form of vegetation, based on some type of photosynthesis, it would be active only during the day, and every night it would pass into a dormant state or hibernation because of the extremely low temperature. If the ancient oceans have not disappeared completely and are now frozen and covered with a thick layer of dust, there might be a water table below this ice layer, because of increase in temperature with increasing depth. Possible life in this aphotic marine environment, based on chemosynthesis, would not be exposed to the severe climatic day-night surface variations and might be manifested in a low-level, nonrhythmic metabolism.

Mars will probably be the only postlunar target for this century, unless new evidence is found by modern astronomy--such as rocket-and-balloon astronomy--that some of the other planets (Venus, in particular) are accessible to manned landing missions. Be that as it may, the physiological clock, manifested in circadian rhythmicity, will play an important role for health and performance in man's conquest of space. Furthermore, its study under nonterrestrial cosmic conditions may shed some light upon the true nature of this biorhythmic phenomenon, which is still far from being completely understood.

A NEW LOOK AT MARS: BIOLOGICAL ASPECT*

Hubertus Strughold, M.D., Ph.D.

The Red Planet, Mars, has come recently again into the focus of general and scientific attention by the planetary probe Mariner IV with its 50-minute fly-by mission on July 14, 1965. Before this historic achievement of the new and fast-developing space-bound rocket astronomy, our knowledge about Mars' atmosphere and surface features had been gained by Earth-based telescopic astronomy. And before the introduction of the telescope into astronomy by Galileo Galilei, 1610, this "wandering star"--conspicuous because of its reddish color--was looked upon as an ominous sign throughout the Middle Ages, dating back to the ancient astrology of the Romans and Greeks, and was named after the god Mars, the symbol of War. But Mars was also venerated as the patron god of agriculture. Strangely enough, this generally not so well known symbolic association with a peaceful occupation foreshadowed, so to speak, a modern aspect of Mars as a plantlife-harboring planet, inspired by telescopic observations of dark bluish-green areas, covering about 25% of the otherwise ochre-red surface.

The famous report by Giovanni Schiaparelli (Milano, 1877) of his observation of canali on Mars, led Percival Lowell (Flagstaff, Arizona, 1906) to the assumption that there might be intelligent beings on that planet. This belief is no longer held, but the possibility of some vegetation on Mars has been the subject of many publications, with pro and con arguments during the past decades. The search for extraterrestrial life applied to Mars is called Mars biology. It plays presently the dominant role in what is variously termed astrobiology, exobiology, and cosmobiology.

Moreover, with the fast development of astronautics during the last two decades, Mars is considered the first postlunar target for a manned-landing mission. An evaluation of its environment from a human physiological or medical point of view, therefore, is becoming an important task of what we might call Martian environmental medicine, or briefly, Mars medicine, which can be regarded--together with terrestrial environmental medicine, space medicine, lunar medicine, etc.--as a subdivision of an all-embracing "cosmic medicine."

A new look upon the environment of Mars as we see it since the Mariner IV mission, the results of which have opened new vistas, has

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*Lecture to the Bioastronautics for Space Research Pilots, Class 66B, Brooks AFB, Texas, 5 August 1966.

confirmed older theories, and requires a revision of others. But, in a brief lecture only one of the life-science aspects can really fruitfully be discussed, and since you have heard so many medical and physiological lectures in this course, I have chosen--instead of the medical problems involved in a manned Martian mission--as the topic, the general biological question of the possible existence of life, or of a biosphere, on Mars.

The term "biosphere" (C. de Lamarck, W. I. Vernadsky) is used for those regions on Earth in which organisms are found. It is also applied to denote the organic nature as a whole (E. Suess). For the highest level of the terrestrial biosphere, distinguished by intelligence and represented by Homo sapiens terrestris, the term "noosphere" (from Greek: noos=mind) was recently suggested (Chardin).

Ecological Criteria

To obtain a picture of the suitability of the planets as abodes for life of the kind we know, which is based on carbon as the structure atom and on water as the solvent medium, we must examine whether or not the fundamental biophilic chemicals (particularly oxygen, carbon, nitrogen, and water) are present and if certain vitally important energies such as radiation are found in the proper tolerable range and intensity. To qualify as a life-supporting environment, these physical and chemical factors must lie above the ecologically required minimum (law of the minimum, J. von Liebig), and should not exceed the permissible maximum. The minimum and maximum are the so-called cardinal points on which the ecological "law of limiting factors" (F. F. Blackman) is based. Beyond these two points life is still conceivable in a dormant state. It would find its terminus at another cardinal point: the ultimum.

In addition to the presence of life-supporting, biophilic chemicals and energies, the occurrence of toxic material must be included in an ecoenvironmental analysis. All of these basic ecological criteria refer not only to the conditions in the wide-open surface spaces (macroenvironment), but also, or better, particularly to those found in localized places such as craters, valleys, pores of the soil, etc. (microenvironment).

Finally, we must also consider the power of life to adapt to hostile environmental conditions by developing life-supporting and protecting mechanisms, and the influence of a biosphere upon the physicochemical environment.

Interpretation of the Dark Areas

The Martian Life Theories have been stimulated by and are concentrated upon the dark surface areas called maria, or seas. What has been and is the interpretation of these dark areas? Their seasonal color variations, from dark gray in winter to bluish-green in spring and brown in fall, suggested vegetation as the background of this phenomenon. But there are some arguments about the bluish-green color.

To some observers they always appear dark gray. In this respect it must be emphasized that a prerequisite for the reliability of any astronomical color observation is a medically tested normal color vision of the observer (7% of the male population is color defective).

The blue-green color is also considered to be a visual-contrast phenomenon against the reddish surroundings. Visual-contrast effects probably occur, especially if the areas are small, but the blue-green coloration of the large areas such as the Syrtis Major in all probability is real. This is supported by the observation of C. Tombaugh, discoverer of the planet Pluto, who recently reported that certain areas occasionally look dark when others look green, despite the fact that both are surrounded by reddish areas. But being green, or not green, is not decisive for life "to be or not to be" on Mars.

There are also inorganic-chemical interpretations of the dark areas. They have been explained as products of volcanic activity, and their color changes have been interpreted as being caused by reactions of the lava to variations in humidity or to intensity fluctuations in radiation.

It has also been suggested that all color changes on Mars can be explained by interactions of nitrogen oxides (nitrogen dioxide and nitrogen tetroxide), depending on solar irradiance fluctuations. These chemicals, considered to be present in the atmosphere and on the ground, are toxic and might exclude life. But the concentration of these nitrogen compounds might be even higher in the smog over big cities on Earth.

Suppose there were intelligent creatures of high scientific-technologic level on Mars and they were able to make spectrographic studies of the neighboring blue-green planet Terra in the search for extra-Martian life. They too might detect nitrogen oxides--in certain smoggy, foggy areas of Earth. They probably would come to the conclusion that if there is life on Earth, it could not be in these foggy spots, which they might interpret as volcanic eruptions. Of course, they could not know that the foggy spots are the product of many millions of exhaust pipes of vehicles of the highly mechanized terrestrials.

Finally, there are some organic-chemical interpretations of the dark areas which have made some impact upon the Martian Life Theory. Ten years ago spectroscopic absorption bands in the infrared, near 3.6 μm, were observed, but only over the dark areas. At first this was considered to be an indication of the presence of organic molecules. Later, however, it was found that they conform just as well with the absorption bands of certain inorganic molecules, particularly of heavy water (deuterium).

And, last but not least, occasionally on Mars heavy dust storms occur, as was the case in 1956. The whole planet then appears reddish. But several weeks later the dark areas reappear. The explanation for this, according to H. G. pik, only can be that the dark material must have regenerative power, which points to vegetation. So much about the visual, chemical, and biological interpretation of the so-called maria.

Ecological Evaluation of the Martian Environment

Now, let us briefly examine the Martian environmental conditions in terms of the aforementioned ecological principles of limiting factors from the point of view of terrestrial biology. Such an analysis has to consider essentially the physicochemical conditions of the atmosphere and the surface, or the interface between these two environmental spheres.

Air Pressure and Chemical Composition. The earlier estimations of the atmospheric pressure at ground level on Mars ranged from 85 to 10 mbars. The occultation experiment of Mariner IV suggests a pressure of 10 to 5 mbars. If we assume a barometric pressure of 10 mbars in the lowlands, this would be pressure equivalent to that of 30 km altitude in Earth's atmosphere.

The atmospheric chemical composition includes carbon dioxide, nitrogen, argon, water vapor, and "traces" of oxygen if any. Formerly nitrogen was considered the dominant constituent. Recent evaluations put carbon dioxide into first place.

That oxygen is practically absent in the Martian atmosphere is certainly a life-limiting but not excluding factor. It is true that O_2 is the "element of life" (Lavoisier) for most species of the plant and animal kingdom, and for man, because their metabolic energy production is based on oxidation (oxybiosis). But there is also a large group of bacteria (anaerobic bacteria) that do not need, or are even sensitive to, oxygen (anoxybiosis). Their metabolism is regulated by enzymes; they would feel at home on an anoxic Mars. Furthermore, if chlorophyll-bearing organisms should exist on Mars, they could produce their own oxygen photosynthetically and might accumulate it in intercellular air spaces, similarly as found in the leaves of terrestrial higher plants and within lichens and mosses.

One of the basic raw materials for photosynthesis is carbon dioxide. In Earth's atmosphere the carbon dioxide pressure is 0.4 mbar; on Mars it might be 10 times as high. The polar ice caps are now assumed to be a mixture of dry ice and water ice. A higher carbon dioxide concentration on Mars would be of advantage for vegetation growth since carbon dioxide in a higher range, up to 15 mbars, increases photosynthesis.

The other basic raw material for photosynthesis is water. But more than this, H_2O serves as the diluent of salt and organic substances and as a chemical reactant in cellular metabolism, and has been the matrix medium for the origin and evolution of life on proto-Earth. In the Martian atmosphere water vapor is extremely scarce. It amounts to only 0.001 of that of the terrestrial atmosphere. In certain deserts on Earth there is no great difference in this respect, and yet botany knows of many so-called desert plants that are able to store water in their tissue and have developed membranes to prevent evaporation. From the point of view of chemoecology and hydroecology, life on Mars would be very limited, but not impossible. We now proceed to the life-supporting energies.

Thermal Energy and the Resulting Temperature. The solar constant at the mean orbital distance of Mars is 0.85 cal/(cm^2·min). If we allow 20% for absorption by the Martian atmosphere, then solar thermal irradiance at the surface of Mars at noon might still be about 0.6 cal/(cm^2·min). Exposed to this thermal influx, the surface of Mars can reach, maximally, in the afternoon a temperature of 25°C. The dark areas are some 5°C warmer. During the night, before dawn, the temperature drops to a -60°C and lower.

Could life as we know it tolerate such a broad temperature range? During most of the daytime in the equatorial regions on Mars, the temperature is ecologically adequate. The low night-time temperatures are the critical ones. Active life processes in terrestrial biology cease around -10°C. Most organisms do not survive, but others enter a dormant state (hiberation). Moreover, there are bacteria that can survive a temperature close to absolute zero.

Protection against frost could be imagined if Martian plants were able to produce some kind of antifreeze such as glycerol as a metabolic by-product. In fact, some of our terrestrial lichens contain erythrol, which belongs to the same class of chemicals as glycerol. All this would be of interest to cryobiology (low-temperature biology), a new subdivision of biology.

But locally there might be exceptions in the form of permanent warm spots on the Martian surface similar to those found on Earth; for instance, on Mt. Wrangell, Alaska, there is a perenially warm, snow-free volcanic sand area surrounded by snow and glaciers, 4211 m high. The Aerospace Medical Division, Brooks AFB, Texas, in 1964, constructed a laboratory there which does not require any heating at any time; it utilizes thermal output of an inactive volcano. There are no reasons why similar permawarm spots might not exist on Mars, which would not have the extreme low temperatures during the night.

Thermoecologically, in terms of terrestrial biology the climate on Mars during daytime should be no obstacle to very hardy, cold-resistant microorganisms and even lower plants.

Light. Although an important ecological factor for life, many microbes can get along without light, as demonstrated by those found in caves, pores of the soil, underground water, and in the deep sea. Chlorophyll-bearing plants, of course, require light energy for the photosynthetic buildup of organic matter.

The minimum illuminance requirement for photosynthesis lies around 2,000 lux. Solar illuminance at the mean orbital distance of Mars amounts to 60,000 lux (lumens/m^2). After penetration of the atmosphere at the surface of Mars, it might still be in the order of 30,000 to 40,000 lux. There should, therefore, be enough light daily for photosynthetic activity.

The low density of a 10-mbar atmosphere, as indicated by the occultation experiment of Mariner IV, might not provide effective protection from harmful solar ultraviolet radiation and X-rays, it is argued; but we must remember that solar irradiance at Mars' distance from the Sun is less than half of that at Earth's solar distance. Furthermore, a certain amount of these rays is certainly absorbed within the atmosphere. From biological research it is well known that ultraviolet rays, particularly in the range from 2500 to 2800 Å, are indeed very destructive to most terrestrial microorganisms. For this reason these rays are used for sterilization of food and ventilating ducts, and for sterilizing lunar and planetary landers to prevent contamination and back contamination. But there are various degrees of resistance to ultraviolet rays, due to protective membranes, etc. Moreover, certain resistant microorganisms are even stimulated in growth when exposed to low-intensity solar ultraviolet radiation and X-rays. And, finally, it has been observed that microorganisms, plants, and animals are less susceptible to ionizing radiation under hypoxic and hypothermal conditions; this is particularly interesting with regard to Mars with its oxygen-poor and low-temperature milieu. All in all, solar ultraviolet and X-radiation cannot be regarded as a life-excluding factor on Mars, particularly in the somewhat protected microenvironments. The same should be true concerning energetic particle rays (cosmic rays).

I should like to emphasize that we cannot consider these various ecological factors separately; there are interrelations insofar as one factor can moderate the destructive effect of another, as in the example of radiation tolerance under hypothermal and hypoxic conditions. Furthermore, a biosphere, as such, can change the physicochemical properties of the atmosphere and of the soil, transforming the latter into humus, which is mineralized decayed organic matter. Considering all of these factors and their intercorrelations, plus the more moderate microclimate, plus the adaptive power of life, we must come to the conclusion that the prospects for life on the Martian surface are more in the realm of probability than of possibility.

This conclusion is also supported by laboratory experiments in which most of the Martian environmental conditions are simulated.

A number of bacteria and even some lower plants not only survive but multiply and continue to grow in such Mars chambers.

In summary, most of the Mars researchers are in favor of the Martian Life Theory, and a nonbiological interpretation of the dark areas does not exclude the possibility of life. Nevertheless, after Mariner IV Mars' pictures were released, some doubt was raised. The main pessimistic argument referred to the dry, water-free, cratered surface of Mars, with no visible water erosion, appearing more Moon-like than Earthlike. In this connection, I would like to discuss briefly a somewhat forgotten theory about the water problem on Mars, or the Martian hydrology. For this purpose we must take a deeper look at Mars; namely, below its surface.

Mars is indeed generally considered to be a "dried-out" planet. It has lost its ancient oceans into space. But A. Baumann (Zurich, 1910) suggested that these oceans are now frozen and covered with solidified dust. Along the same line, H. E. Suess (Chicago, 1957) stated that "substantial quantities of water may be buried under dust and never become volatile at the low temperature of parts of the planet." This frozen-ocean theory has been revived recently by V. D. Davydov (Moscow). He theorized that there might be a subsurface ice layer 500 meters thick in the equatorial regions. Beneath this "frozen conglomerate," or cryosphere, water might be found in the liquid state due to an increase of temperature in the interior of Mars. And when cracks in the ice layer occur, caused by Marsquakes, water may reach the surface and produce localized giant clouds and white streaks of fog lasting several days, as have been described by P. Lowell and E. C. Slipher. White spots glittering like ice have been observed in the equatorial regions by Saheki (Tokyo). More probable than quakes of volcanic origin, impacts by giant meteorites of asteroidal origin could be considered as causes of craters and cracks in the soil-covered frozen hydrosphere, or hydrocryosphere.

In this connection, an hypothesis advanced by P. A. M. Dirac (London, 1937) might have some significance concerning the mysterious canals. According to this hypothesis, the gravitational constant has decreased during the life of the solar system and continues to decrease. This has led to an expansion of Earth, causing "tension cracks" or fissures on land and at the bottom of the oceans, as recently described by R. H. Dicke, Cornell University, and P. Jordan, Hamburg University. The splitting of two giant original supercontinents, Gondwanaland and Laurasia, about 1 billion years ago, into several secondary continents, now widely separated by "continental drift" (A. Wegener), is attributed to this gravitational phenomenon.

It is logical to assume that on Mars, too, this gravitational decrease has caused similar effects; namely, volume expansion and tension cracks. And meteoritic impacts should have produced fissures of tremendous dimensions in a crust of different layers. This might well have been the mechanism behind the scene of the dark spots called oases and the dark linear markings radiating tremendous distances from the dark spots.

The existence of a subsurface ice and water table on Mars would increase the humidity locally; i.e., in and around the meteoritic impact craters and fissures, making them ecologically more suitable for the growth of vegetation. Actually, it might be the soil's humidity and vegetation that made these areographic surface features visible in the first place to Earth-based optical astronomy.

And, last but not least, a subsurface ice layer, or hydrocryosphere, on Mars would represent a hidden reservoir for continuously replacing the small amount of water vapor in its atmosphere; otherwise, all of the water molecules might have disappeared into space in the course of millions of years (Barabashov).

Moreover, if there is a water layer below the ice layer, then in addition to the surface biosphere there could be a subsurface habitat for life. Life of microorganisms in such an aphotic, hyperbaric, deep-sea environment might be based on chemosynthesis--in contrast to that on the Martian surface, which might be based on some kind of photosynthesis.

By the way, from the point of view of Mars medicine, or bioastronautics, a subsurface ice layer, or hydrocryosphere, would represent a "gold mine," logistically, for a manned Martian expedition.

All of this might be termed wishful thinking on the part of exobiology and Mars medicine, especially now in the light of the close-up pictures of Mariner IV. Their initial interpretation was that the "visible Martian surface is extremely old and that neither a dense atmosphere nor oceans have been present on the planet since the cratered surface was formed."

Later evaluations of Mariner IV photographs, however, considered the surface of Mars to be only about 300 to 500 million years old, and led to the statement that "the crater density on Mars no longer precludes the possibility that liquid water and a denser atmosphere were present on Mars during the first 3.5 billion years of its existence (E. Anders and Y. R. Arnold). Thus, the ancient ocean theory might be correct after all. It might be that some 300 to 500 million years ago, Mars, after it had lost most of its water into space, entered a permanent ice age and that the frozen remaining ocean, in the course of millions of years, was covered by a deep layer of dust that became solidified and was bombarded by numerous asteroidal meteoroids, starting with the disruption of Planet X--the matrix planet of the asteroids, some 300 million years ago. This might explain the face of Mars that we see today.

Of interest concerning humidity are the hoarfrost-crowned craters in some of the Mariner IV pictures, and a white spot with a dark spot at one side in picture 14 which looks like a big cloud casting a shadow below. Several prominent Mars experts, such as Tombaugh and de Vaucouleurs, definitely recognized, in several pictures, linear markings and oases that coincide with similar ones known to them from telescopic observations. Another interesting result published was that a certain reddish area called Electris seemed to be 5 km higher than a dark area called Mare-Acidalium. Thus, the reddish areas seemed to be highlands, the continents of ancient times. The dark regions, then, are the lowlands covering the low-level remnants of the ancient and now frozen ocean. It is only logical to assume that the dark lowlands have a higher soil humidity due to the underground ice table and thus offer an ecologically more favorable matrix for the existence of a Martian biosphere.

But most of this is still speculation. What we need now is on-the-spot exploration. In the years ahead automated life-detecting devices will be sent to Mars to acquire and analyze soil samples and transmit the data to Earth. But the final answer concerning a Martian biosphere might come from a manned expedition. Only Martianauts, protected by pressure suits, walking around outside the Mars station will be able to select different surface areas and bring back samples to its research laboratory and later to Earth. Only they will be able to take a deep look at rock formations in fissures and craters, which might give us some information about the paleological evolution of life on Mars.

If some day the question of extraterrestrial life is answered in a positive sense--and the answer may well come from Mars--this will not be the news of the century, not the news of the millennium, it will be <u>the news</u> of the recorded history of mankind. Moreover, it will extend the Earth-related Cenozoicum (the recent geological era) into a universal spectrum--the Cosmozoicum.

INTERNAL ATMOSPHERE

Hubertus Strughold, M.D., Ph.D.

Internal atmosphere is a concept that originated in biology; it refers to a body of air contained within an organism itself and in communication with the external atmosphere. This phenomenon is found in all realms of the living world. In man and animals it serves the purpose of gas exchange in the processes of respiration and transpiration; in plants it serves additionally for gas exchange in carbon dioxide assimilation, or photosynthesis. Without a doubt, it represents a biological, or more precisely, an ecological principle of great significance in the development of living beings.

The phenomenon of internal atmosphere has become the basis for experiments in respiratory physiology and, more recently, for high-altitude research in aviation medicine. For these reasons a synoptic study of the internal atmosphere is most apropos.

The Morphological Picture

Animal Kingdom. When the body surface of an organism is large in relation to its mass and the stage of development is primitive, the body surface is adequate for gas exchange in respiration. With a decrease of the ratio surface to mass (S/M), the outer skin becomes insufficient as a respiratory surface, and the development of a specific respiratory area on a larger scale takes place. This is accomplished first by localized folds of the extoderm, or gills. These gills appear in the primitive stage in annelides and molluscs, are developed to a greater degree in crustaceans and fish, and are recessive in the amphibians. All of these animals live in water or in very humid air.

With the transition of these animals to dry land, the development of the respiratory surface turns to the interior, and by this process we arrive at the lungs of vertebrates and the tracheal system of insects. The lungs are invaginations of the entoderm. Insofar as their surface is concerned, they are manifested in three stages:

(a) Simple lung sacs (lungfish, newt)

(b) Spaces divided by septa (frog)

(c) Alveolar structure (warm-blooded animals)

In man, the alveolar structure reaches a respiratory area of 60-100 m^2. The air body (alveolar air), which in this way is interposed between the blood and the outer atmosphere, amounts to about 3 liters. It is noteworthy that oxygen pressure in this air body represents only two-thirds that of the external air, and that carbon dioxide pressure is 100 times greater than that of the outer atmosphere. This air body is the proper atmosphere for the body fluids and cells to be in direct gas exchange. This internal atmosphere, however, becomes the ambient milieu for bacteria and virus if they are inspired into the lungs. We shall return to this important point later.

While the lungs are ontogenetically invaginations of the entoderm, the tracheae of insects are invaginations of the ectoderm. These animals show up to 10 pairs of openings on both sides of the body. These stigmata or spiracles lead into air-filled tubes (tracheae), which in turn branch into very fine tubes (tracheolae) and finally end between, or even within, the body cells. Gas exchange between the inner atmosphere within this system of tubes and the tissue, is achieved by way of diffusion. For gas exchange with the outer atmosphere, diffusion is sufficient in primitive insects (diffusion tracheae). In higher insects, ventilation movements become necessary (ventilation tracheae). In many insects the tubal system is connected with air sacs. Little is known about the chemical composition of the tracheal air. It has been found that the oxygen content is some percent lower than that of the atmosphere. The tracheal system is somewhat similar to the airing system found within the leaves of plants. Indeed, one might even call it plantlike.

Plant Kingdom. In the plant kingdom, the internal atmosphere is of interest in this discussion only insofar as it is found in the intercellular spaces of the leaves. The labyrinthine arrangement of these spaces leads to an enormous enlargement of the internal surface, which may reach 10 to 30 times that of the outer leaf surface. With the ambient air the "aerenchyma" is in communication through microscopically small openings (stomata) of which up to 100-300/mm^2 occupy the upper or lower side of the leaf. These pores are adjustable, the humidity of the air being the regulating factor. In addition to respiration and transpiration, in plants the internal atmosphere serves the purpose of photosynthesis. Oxygen produced in this process during the day is stored in the intercellular air spaces so that the plant can consume it for respiration during the night. Indeed, analysis of the intercellular air yields an oxygen content of 30 to 60 volume percent. This means that the plants, temporarily at least, live under higher oxygen pressure than that of the atmospheric air. Furthermore, the intercellular air spaces store carbon dioxide expired during the night, to be used for photosynthesis during the day. The significance of these spaces for water balance, however, cannot be discussed here.

Intercellular air spaces are to be found in all plants down to the thallophytes. However, true pores are not yet present, but only indications of them in the form of a localized loosening of the otherwise very dense mycelium (Cyphellae). In the next higher subdivision--the bryophytes, however, we find true adjustable pores, each of which belongs to an air compartment (liver moss). So much for the occurrence of internal atmosphere in the world of plants. Further information can be found in the textbooks and handbooks on zoology and botany.

Thus, the phenomenon of the internal atmosphere, as we have just seen, extends through a great part of the living world. Without a doubt, it represents a physiological-ecological principle of general significance which may be summarized in two points:

(a) By the principle of the internal atmosphere, the area of gas exchange of the organism is brought into balance with the need which results from rising organization and increasing mass, and

(b) The internal atmosphere serves as a buffer against variations in climate and, with some exceptions, facilitates existence under extreme environmental conditions.

These points may lead to various considerations, as follows:

Paleobiological Aspects

As previously mentioned, the phenomenon of internal atmosphere has already existed in the primitive plants such as lichens and mosses. Fossil lichens and mosses are found in the early Paleozoic, or Paleophytic, era. Therefore, in all probability, as early as 500 million years ago we can trace the appearance of internal atmosphere in plants. The possibility of its existence in the Proterozoic and Archeozoic eras cannot be excluded. Actual proofs are missing for these justly called "cryptozoic" eras. The phenomenon of internal atmosphere is fully developed in the later appearing vascular plants.

In the animal kingdom, internal atmosphere in the form of lungs came into existence for the first time in the early Devonian period (320 million years ago). It was the lungfish that introduced the epoch of internal atmosphere within the realm of animals. They probably existed even in the Silurian period (350 million years ago). Living fossils of this kind are preserved in the lungfish of Australia (Epicerodus), of South America (Lepidosiren), and of Africa (Protopterus). Amphibians with simple lung sacs (newt) appeared in the Devonian period; while others with subdivided sacs in the Carboniferous period (300 million years ago). The development of the alveolar structure of the lungs may have taken place in the Permian period (240 million years ago).

For the benefit of completeness, it may be added that from the phylum Mullusca, the order of Pulmonata developed the principle of internal atmosphere in the Carboniferous period. Finally the tracheal system may have come into existence in the Silurian period; the millipods, which are provided with such an aeration system, appeared in this period. In the Devonian, the first wingless insects followed. (See the palaeontological time table.)

If we assume that living beings have existed on Earth for 2 billion years, then the phenomenon of the internal atmosphere has been in existence only during the last quarter of this time and therefore is a relatively recent acquisition. This is the foundation on which warm-blooded animals have attained the fullness of life. It is the prerequisite for such higher development as establishing a thermal regulation and achieving the ability to walk upright, to fly, and to attain the higher activity of the brain. All of these were developed with relatively great speed. In the plant realm, too, internal atmosphere was necessary to bring about the luxuriant development of vegetation--from the primitive level of thallus plants up to the blossoming plants of today.

The question "Can we draw conclusions from the phenomenon of internal atmosphere about the historical development of the Earth's atmosphere?" may be raised at this point.

In the late Paleozoic period--about 300 million years ago--for the first time insects appeared and developed into giant specimens. For example, the libellula-like meganeuse (dragon fly) had a wing span of 60 cm (2 ft), a length of 30 cm (1 ft), and a chest expansion of more than 2.5 cm (1 in). The insects of today fall far below this size. A. Krogh has calculated that, because of its limited oxygen supply, the tracheal system permits the existence of only relatively small insects. In other words, the tracheal system, apart from the exoskeleton, is a limiting factor in the size of the body. For the giant insects, tracheal respiration might (according to A. Krogh) be just sufficient if we presuppose ventilation trachea, low metabolism, and a mild climate. However, the fact that at one time giant insects did exist and that no such specimens are now in existence, could be due to a different constitution of the atmosphere. It would be very presumptuous to venture the opinion that oxygen pressure was higher at that time than it is today; still, it must be considered that a luxuriant vegetation, which left behind our abundant coal deposits, existed at that time. As is well known, vegetation determines the oxygen content of the atmosphere from the aspect of production. Calculations have shown that the land vegetation of today is capable of producing our present oxygen content in the air (1.2×10^{21} g) in less than 30,000 years. The Carboniferous period (Mississippi and Pennsylvania), however, lasted about 70 million years. The Permian period which followed was characterized by a glacial epoch during which oxygen production was certainly lower.

It would be absurd to assume that the atmospheric oxygen pressure was always the same as today. Oxygen measurements in the atmosphere date back only 150 years, during which time no change in the oxygen content of the air has been found. Considering the shortness of this time span, such a change is not to be expected. A century and a half is less than one 100-millionth of geological time ($2x10^9$ years) and less than one 30-millionth of Phanerozoic time ($5x10^8$ years).

Another paleobiological point may be worthy of mention. The carriers of lungs show a tendency under oxygen deficiency to keep constant the constitution of their alveolar air; for instance, by hyperventilation. It is tempting to compare the constancy of the internal atmosphere with that of certain properties of the blood. The salt content of the blood shows a similarity to that of seawater. It is presumed that this may be a hereditary feature from the epoch of the fishes, and that the amphibians have preserved the chemical constitution of marine animals long after their transition onto dry land. The internal atmosphere of warm-blooded animals may be a relic of the atmospheric constitution of the era when amphibians inhabited the land.

The high carbon dioxide concentration of the alveolar air is very striking. It might point to a higher carbon dioxide pressure of the atmosphere in former times, as has occasionally been assumed in literature. If this assumption is correct, it could mean that man still carries a bit of the Paleozoic era in his chest.

Medical Paleobiological Aspect

Returning to the earlier statement that the internal atmosphere becomes an environmental millieu for bacteria and viruses if they are inhaled; in this respect, the internal atmosphere offers an interesting medical paleobiological aspect. Bacteriological studies have revealed that an increased concentration of carbon dioxide generally promotes the growth of bacteria. For many bacteria the optimum lies between 5 and 10 volume percent of carbon dioxide.

That pneumonia strikes down a man of good health within a few days is not surprising, because its agents find an ideal carbon dioxide environment in the internal atmosphere for explosive development. The carbon dioxide optimum of bacillus tuberculosis lies between 2 and 3 volume percent. According to the opinion of many geologists, the bacteria virus, algae, and other low organisms were the first and only organisms in the Proterozoic era, at a time when the carbon dioxide pressure was higher than it is today.

Paleologically, carbon-dioxide-philic bacteria are perhaps very old organisms. If so, when inhaled they return into their own medium which has been preserved from the Proterozoic era within our inner atmosphere. Considered from a similar point of view, the origin of an aerobic bacteria may go back to that time when the atmosphere contained little or no free oxygen. These possibilities may merit attention from the medical as well as from the paleobiological aspects.

Aeromedical and Space-Medical Aspect

Flight to higher altitudes has made the internal atmosphere an especially important topic in aeromedical research. The fact that the alveolar air always shows a relatively high carbon dioxide pressure (40 mm Hg) and water vapor pressure (47 mm Hg) causes hypoxia to increase much more rapidly with increasing altitudes than it should according to the oxygen pressure of inspired air or inhaled oxygen. The constitution of the alveolar air, therefore, is a more accurate criterion of the degree of hypoxia than the ambient air, and consequently is an important physiological basis for high-altitude research.

The study of the alveolar air shows the interesting fact that its oxygen pressure becomes zero at an altitude of 16 km (52,000 ft), because the corresponding total air pressure (about 87 mm Hg) is comprised of carbon dioxide and water vapor only. At least atmospheric oxygen, still present in these layers of the outer atmosphere, is prevented from entering the alveoli because of the presence of the other gases. This means that above such an altitude, flyers not protected by a pressurized suit or a pressure cabin, would be subjected to complete anoxia; however, below this altitude they would find themselves in the state of hypoxia.

Thus, the consideration of the principle of the internal atmosphere may help to clarify the terminology of oxygen deficiency (hypoxia-anoxia), which differs greatly in physiological and aeromedical literature. From the space-medical point of view with regard to oxygen, the example demonstates that above 16 km (52,000 ft) we find ourselves practically in space. On the basis of the alveolar air--or in other words, of the internal atmosphere, this altitude is space-equivalent. This subject has been discussed in detail in another paper.

In contrast to these considerations, the phenomenon of the internal atmosphere could also facilitate the tolerance of extreme atmospheric conditions. This has already been discussed regarding chlorophyll-bearing plants. From the aspect of physiology, if the hypothetical vegetations on Mars, where the atmosphere is found to contain sufficient carbon dioxide but no oxygen, were to develop features similar to those of terrestrial vegetation in the form of the internal atmosphere, then the objections to their existence would lose weight.

Summary

The existence of internal atmosphere in the living world has been discussed: in the plant kingdom, in the form of the intercellular airspaces of the leaves; and in the animal kingdom, in the form of the tracheae in tracheates and in the form of lungs in fish, amphibians, reptiles, mammals, and birds. Special attention has been given to the

internal atmosphere of man (alveolar air). The wide distribution of the principle of internal atmosphere gives it the significance of a general biological principle. This has been explained from the viewpoint of paleobiology, medicine, aviation medicine, and space medicine.

LIFE IN A THEORETICAL ZONE BELOW THE SURFACE OF MARS*

Hubertus Strughold, M.D., Ph.D.

Ever since the announcement by Schiaparelli in 1877 that he had observed straight lines, which he termed "canali" (channels), in geometrical patterns on the surface of Mars, astronomers and biologists have searched for evidence of life on that planet. According to our present knowledge of environmental conditions on the larger bodies in the solar system, Mars appears to offer the best promise of finding an indigenous biology elsewhere than on the Earth (1).

Recent hypotheses have concentrated on the dark, blue-green areas which comprise about 25% of the Martian surface. Occurring mainly in the lowland regions known as maria, or seas, these areas show marked seasonal variations in color. For that reason, many investigators have concluded that they represent some type of vegetation. The principal objection to this belief is founded on the question as to whether Mars provides water in sufficient quantity and distribution to support a well-developed plant cover.

Lowell established the prevailing picture of Mars as a nearly desiccated planet (2). He considered the maria to be dry beds of former oceans, from which the water evaporated and was lost into space because of the low gravitational attraction of Mars. Kuiper (3) and others have determined that a small amount of water vapor remains in the atmosphere, estimated at 1% of the water vapor in Earth's atmosphere, or less. Some of this vapor condenses periodically around the poles, forming thin deposits of ice or snow.

Lowell thought that the canali were bands of vegetation, following artificial canals. He believed that the canals had been constructed by intelligent beings at some time in the past, to carry water over the planet from the polar caps as they melted in the spring. This opinion is no longer held. There is substantial doubt as to the existence of the canali, and whether, if they do exist, they are as geometrical in plan as Lowell saw them.

The accepted view continues to be that Mars is extremely arid, although it may retain enough water to support a very hardy and perhaps primitive species of plant life. However, some observational evidence has been found to suggest an alternative model of the hydrographic situation on Mars.

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*Written in 1964.

White Spots

As long ago as 1879, Schiaparelli referred to brilliant white spots resembling ice fields on the surface of Mars, in areas far removed from the polar caps. Lowell described this phenomenon in a lengthy discussion (4) which may be summarized by the following excerpts:

"In addition to the polar caps...*other white spots* may from time to time be seen upon the disk....They sparkle on occasion in like manner with the sheen of ice....Their duration is reckoned by weeks and even months....All of the above instances of extra-polar white have been located within the tropics. Examples of the same thing, however, occur in the north temperate zone." Of one such spot in latitude 50° N, Lowell wrote: "This spot, too, on occasion glitters, as it were, with ice." He interpreted these occurrences as hoarfrost, resulting from local drops in temperature.

Slipher later photographed a very large spot of this type, and reported its appearance in a paper (5). He wrote that the spot was "800 miles long and 400 miles wide, slightly less bright than the south polar cap but more brilliant than the north cap, and in tint slightly more yellowish than the south cap." He called this spot, which disappeared after several days, "an outstanding feature in the recorded history of Mars," concluding that "it is of most pertinent significance regarding conditions on the planet."

Somewhat similar to these were the mysterious white strips observed by Barabashov (6). They extended over the ground for distances of 100 to 1,000 km. Barabashov did not attempt to explain them. Also similar were the bright flares reported on the disk of Mars a few years ago by Saheki in Japan (7). These, too, were interpreted as the effect of sunlight reflected from sheets of ice. They were followed by the formation of clouds in the atmosphere.

The Ice-Mantle Theory

A possible explanation of these bright areas resembling ice fields on the dry surface of Mars may be found in a theory advanced by Baumann more than half a century ago, to account for the apparent absence of liquid water (8). He postulated that the primordial oceans had frozen and had been covered by an accumulation of dust from active volcanos. Baumann held that the ochre areas--generally identified as desert highlands--were the former seas and that the dark areas were continents. The canali were attributed to fissures in the ice, also resulting from volcanic action.

According to this view, Mars would contain an extensive ice mantle, covering about 75% of its area, beneath a surface layer of pulverized soil. In a statement repeated by Urey (9), H. E. Suess also has suggested that "substantial quantities of water may be buried under dust and never become volatile at the low temperature of parts of the planet."

In Moscow recently Davydov has developed the ice mantle theory in greater detail (10). He assumes that the planetary materials from which Mars evolved included water in approximately the same proportion to their total mass as did those from which Earth was formed. Because of the greater distance of Mars from the Sun, most of this water is now frozen. The ice mantle is hidden under an envelope of dust deposited by the frequent dust storms that sweep across the planet. Davydov considers that the polar caps are exposed areas of the mantle.

This is by no means a radical idea. Many authorities now believe that the large satellites of Jupiter and Saturn may be encased in outer shells of ice. Even at the relatively near distance of Earth from the Sun, Gold has suggested that the Moon may have an ice table at a depth of 30 m below the visible surface (11). The Moon today is regarded as a totally dry body with no more than a trace of atmosphere. Yet patches of mist that resemble water vapor escaping from the interior have been reported.

So it should not be taken for granted that Mars, because of its inferior mass, has necessarily been divested of nearly all its water. If the temperature conditions under which it evolved were suitable, Mars could possess an ice mantle of considerable depth below its generally bare and arid surface.

Underground Water

Davydov goes beyond the possibility of frozen water under the Martian surface. He estimates that the temperature increase in the interior of Mars follows nearly the same pattern as the temperature rise within Earth. Under the surface of Earth, the increase is approximately 3°C per 100 m of depth. If this is the case on Mars, then in the tropics, where the mean annual surface temperature is -15°C, the temperature within the crust would rise above the melting point of ice at a depth of only 500 m below the surface. In the polar regions, where the mean annual surface temperature is much lower, the melting point would be reached at a depth of perhaps 2,000 m.

Within Earth's oceans, the temperature gradient is not the same as in the crust. Warm water rises toward the surface while cold water descends toward the bottom, resulting in a circulation that localizes and reduces the overall temperature variation. However, it is to be expected that the temperature in the crust would determine the depth at which a frozen sea would melt. If Davydov's assumptions are correct, there should be a reservoir of liquid water below the subsurface layer of ice on Mars. Then assuming that fissures appear in the ice from time to time as a result of stresses in the mantle, some liquid water would ascend toward the surface. Upon meeting the rarefied atmosphere above, the water would evaporate, forming vapor clouds or streaks of fog, or depositing hoarfrost on the ground. This process would explain the brilliant white spots described by Lowell and Slipher, the white strips reported by Barabashov, and the bright flares observed by Saheki.

One possible source of stress violent enough to open deep fissures in the ice would be shock forces from volcanic action, as Baumann assumed. But this is not the only plausible explanation. Another might be impacts by large meteorites, approaching asteroidal dimensions. The proximity of Mars to the asteroid belt has led Tombaugh to propose the likelihood of such collisions (12). In this connection, I have tested the effects of similar impacts on ice beneath a covering of soil by means of a simple experiment. Small models of the Martian crust were made by sandwiching layers of ice between layers of frozen dirt, and were subjected to impacts from bullets. The impacts produced miniature craters with white floors (Fig. 1) resembling the spots described by Lowell and Slipher.

Still another possibility may be mentioned. According to Dirac, the gravitational constant has decreased during the life of the Solar System and continues to decrease (13). The apparent expansion of Earth, causing cracks in the mantle some 10 to 15 km below the surface, has been ascribed to this cause by Jordan (14). It is conceivable that the same process--or any other activity causing the total volume of the planet to expand--might have produced fissures under the surface of Mars.

Whatever its origin, an extensive system of ice fissures under the Martian surface would account for the elusive canali. As Davydov points out, vegetation established along the fissures would have access to a relatively abundant supply of moisture and so might be expected to grow in some profusion. More significantly, a reliable source of underground water would greatly alter the present view of Mars as a marginally habitable planet. It would provide a means of life support for explorers from Earth. Besides, it would open up the possibility of indigenous life on Mars in a type of environment which has not been previously considered.

A Subsurface Biosphere

If liquid water is found in substantial quantity below the surface of Mars, underneath a stratum of ice at depths of 0.5 km or more, it may be considered as a potential biosphere. For life to exist in such a setting, it would have to meet certain conditions, of which the most important by terrestrial standards are pressure and temperature.

With regard to pressure, marine organisms capable of withstanding very great pressures have been found in the Earth's oceans. Various

Figure 1. Simulation of meteorite impact on the surface of Mars.

types of barophilic (pressure-tolerant) bacteria have been recovered from sediments on the bottom of the Pacific at depths exceeding 6,000 m (15). The hydrostatic pressure at this depth is isobaric with 600 atmospheres. Even at 10,000 m (1,000 atm), deposits from the bottom contain bacteria, indicating that terrestrial microorganisms can endure tremendous pressure.

In Earth's oceans, pressure increases by 1 atm with each 10 m of depth. On Mars, which has a surface gravity of only 0.38 g, the hydrostatic pressure would increase by 1 atm every 26 m. Hence, at a depth of 500 m below the Martian tropics, where it has been estimated that an ice table would melt, the pressure would be less than it is anywhere in Earth's deep seas, which begin at 200 m of depth according to the conventional definition. Even at depths of several thousand meters on Mars, the pressures would be well within the range of tolerance for terrestrial microorganisms. It may be added that numerous metazoa, such as starfish, sea cucumbers, bivalves, and others, have been discovered in Earth's deep seas.

With regard to temperature, in terrestrial biology active life is possible from several degrees below the freezing point of water to a maximum of 80°C. At the bottom of Earth's deep seas, the temperature is about 2.5°C. It is estimated that the temperatures in a subsurface sea on Mars would be of approximately the same order of magnitude. Therefore temperature would present no obstacle to life at either end of the scale. It would presumably vary with depth, but nowhere would it show the extreme day-night variation (from 25°C to -50°C and lower) that prevails on the surface of the planet.

A subsurface reservoir under several hundred meters of ice, and covered by a top layer of dust, would of course be permanently dark, except perhaps where some light filtered down through fissures. Light, however, is not a prerequisite for life. Numerous species on Earth live in aphotic environments, including inhabitants of the oceans below approximately 500 m, where sunlight no longer penetrates from the surface. Also in this category are soil bacteria and the different forms of life found in caves, coal mines, and petroleum deposits. Unlike photoautotrophs (green plants which provide the basic substance of life on the surface), they do not rely on photosynthesis to build organic materials.

Dark-Adapted Organisms

Photoautotrophs are not the only kind of life that produces organic matter. Thermoautotrophs, such as purple bacteria, make use of heat radiation for the same purpose. We also have a great variety of chemoautotrophs, deriving chemical energy from oxidative processes. Subtypes of these autotrophs, depending on the oxidized chemical, include hydrogen, nitrogen, methane, ammonia, sulfur, and iron bacteria.

If some of these chemicals, together with oxygen or oxygen compounds, are present in an underground reservoir of water on Mars, the environment would be suitable for chemoautotrophs of the types known on Earth. Moreover, if they exist, they would supply nutritive substances for heterotrophs, which can live only on prefabricated organic matter. The heterotrophs might conceivably have developed by evolution from the original chemoautotrophs.

The supposition that we have been exploring depends upon the answer to a crucial question. Assuming that they once existed in a liquid state, at what period in the formation of Mars as a planet were its oceans frozen? If they began to freeze at a relatively early stage, while the Martian protoatmosphere consisted mainly of hydrogen, ammonia, methane, and water (as the original atmosphere of Earth most probably did), then they might still retain these primordial atmospheric gases in suspension. If so, then the present subsurface water would offer an ideal medium for the chemoautotrophs described above.

Further, it is well within the bounds of plausibility to consider that even organic material might exist on Mars, both in the proposed ice mantle and in the water below. This material could have been produced within the primordial atmosphere by ultraviolet radiation or by lightning, later settling into the water, or it could have been produced in the upper levels of the former oceans. Miller (16) has experimentally demonstrated that organic matter, such as amino acid, can be generated in a protoatmospheric mixture of these gases when electricity is discharged through them. The result would have been a "nutritional broth" of the type suggested by Oparin (17) and others as the original stuff from which life developed on Earth.

It is logical to expect that life would have developed on Mars under similar conditions, assuming that life has arisen there at all. Unless oceans once were present, under a reducing atmosphere with the composition postulated by modern theory, it is difficult to account for the origin of any living organisms on Mars today. The possibility that they may exist now in a subsurface hydrosphere is, of course, a speculation; however, it is more probable that life would have survived in a sheltered environment, providing warmth and an abundance of water, than in the extremely cold and arid climate that characterizes the Martian surface. In fact, the underground environment would contribute to the survival of life on the surface. Besides increasing the flow of moisture over the planet as a whole, the suggested fissures in the ice mantle might serve as channels for occasional intercontaminations between the two biospheres, to the benefit of both.

Summary and Conclusion

The classical view of Mars depicts a planet of such small mass that it has lost nearly all the moisture from its former oceans, by the dissipation of its water vapor molecules into space. Many observers believe that a hardy species of plant life thrives in certain areas, maintaining itself on the residue of this moisture, which circulates toward the tropics from the polar caps during the Martian spring and summer.

A number of puzzling observations have led some astronomers to formulate an alternative theory. They suggest that the original water was not entirely lost, but instead was frozen, forming an ice mantle of considerable depth under a surface layer of dry dust. The lower levels of the mantle may be liquid, due to higher temperatures in the interior. A certain amount of moisture may escape to the surface through fissures in the ice.

A subsurface hydrosphere not only would strengthen the biological potential of Mars as a whole, but also would extend it to another region, previously unsuspected. If life exists in underground seas on Mars, it would have the characteristics of marine biology in the depths of Earth's oceans. Its development could be predicated on present-day beliefs about the origin of life on Earth.

The concept of a marine biosphere on Mars, hidden from direct observation by astronomers, can only be supposition at this time. However, space probes might be designed to shed some light on this suggestion. Every possibility of an environment favorable to life should be examined before human astronauts are landed on Mars.

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THE LIFE ZONE IN THE PLANETARY SYSTEM

Hubertus Strughold, M.D., Ph.D.

The problem of life on other worlds is a subject that captivates the imagination of mankind tremendously. Not until it was recognized that Earth is not the center of the universe, but rather only one of the members of the planetary family of the solar system (Copernicus, 1543), could such thoughts arise in the human mind. There are two technical events that have had a catalytic effect upon man's preoccupation with this question: the invention of the telescope some 350 years ago--which brought the celestial bodies closer to us optically; and recently, the successful development of the rocket--which possesses the potentialities of bringing us closer to them physically. In fact, our chances of reaching neighboring celestial bodies have shifted from the level of possibility and probability to an approaching certainty. This must logically be concluded from the rapid progress in rocketry, space technology, and space medicine. Spurred by these events, the older question of the existence of indigenous life on other planets has come anew into the focus of scientific and general public interest; and with the development of space operations, the particular question is posed: Are there planets in the solar system that offer an environment of such kind that an astronaut from Earth, the species *Homo sapiens terrestris*, could land and stay there for some time at least?

We get an answer to both of these questions by projecting the specifications of the environment required from the standpoint of general terrestrial biology and human physiology against the physical planetary data offered in the astronomical literature. Such a study can be called planetary ecology. For the science that particularly studies the possibility of indigenous life on the planets, the terms "astrobiology" and "astrobotany" are in use. This discussion will consider only the kind of life known to us, based on carbon as the structure atom and on oxygen as the energy-liberation atom.

First, let's take a look at the family of the planets in our solar system. As wandering stars within the multitude of fixed stars, they attracted the special attention of the ancient Greeks and Romans, who bestowed upon these planets the names of their highest deities: Mercury, the messenger of the gods; Venus, the goddess of love; Mars, the god of War; Jupiter, the overlord of all the gods; and Saturn, the father of the gods. Later on, in modern times with the aid of the telescope, astronomers discovered two more planets and gave them the names of Uranus, the god of the Heavens, and Neptune, the god of the Sea. Only 27 years ago, a new planet was discovered by Dr. Clyde Tombaugh at Lowell Observatory in Flagstaff, Arizona, which was given the name of

Pluto, god of the Underworld. Between Mars and Jupiter, there is the belt of the asteroids of minor planets. The planets on the inner side of this belt (like Mercury, Venus, Earth, and Mars) are called the inner planets; those on the outside of this belt are the outer planets. The distance from the Sun to the outermost planet, Pluto, is about 5900 million km (3670 million mi). Within this range, the planets are geometrically spaced in the sense that each successive planet is about twice as far from the Sun as the preceding one, which is known as Bode's Law.

The distances of the planets are of special significance in the question of their qualification for an abode of life. The intensity of solar radiation is the decisive agent in this respect, and since the intensity of solar radiation decreases with the inverse square of the distance from the Sun, the differences between the radiation intensities at the various planetary orbits are tremendous.

As a point of departure, let's choose the radiation conditions as they are found in the distance of Earth from the Sun (149 million km, or 93 million mi). The radiant energy received in this distance by 1 cm^2/min in the form of heat, light, and rays of other wavelengths is equal to 1.94 cal. This value is known by the name "solar constant." According to the inverse square to the distance law, at the distance of the orbit of Mars (228 million km, or 142 million mi) this value decreases to a little less than half. In the area of Jupiter's orbit (779 million km, or 484 million mi) it amounts to only 4% of Earth's value. Pluto, 5872 million km from the Sun, receives per area unit only 0.06% of the amount of energy that Earth receives. In the distance of Venus' orbit (108 million km, or 67 million mi), however, the respective solar constant is more than 150%, and on Mercury (58 million km, or 36 million mi) more than 600%, greater than the value in the vicinity of Earth. Such are the radiation conditions at the mean distances of the various planetary orbits.

When absorbed by such matter as a planetary atmosphere, solar radiation causes both physical and chemical effects within the atmosphere, resulting in specific ecological conditions. These must differ tremendously on the various planets when we consider the radiation variations as a function of the planetary distances just discussed.

One of the most important physical-ecological conditions is temperature. Active life processes are possible only within a certain temperature range, from some degrees below the freezing point of water to about 80°C. Beyond this range, life becomes dormant, or latent, and later perishes. In examining the possibility of life in any medium, the possibility of active life is what counts.

If we now consider the measured temperatures of the planets, as shown in recent astronomical literature, we obtain a set of figures that conform to a considerable degree with the values obtained from the respective planetary solar constants. The temperature on the Sun side of Mercury amounts to over 400°C. That of the atmosphere of Venus varies between +100° and -10°C. On Earth, temperatures between +60° and -60°C are observed. Martian temperatures range between +25°C and -70°C. At the visible surface of the atmosphere of Jupiter, a temperature of -160°C is reported. For Saturn the figure is -180°C; for Uranus, -190°C; for Neptune, -220°C; and for Pluto, -240°C.

Only Venus, Earth, and Mars cover--partially or totally--the range of temperatures biologically required for life as we know it. Beyond Venus, on Mercury, it is too hot; beyond Mars, from Jupiter to Pluto, it is too cold. Thus, we arrive at a temperature belt surrounding the Sun within which active life on planets is conceivable, outside this belt it is not; Venus lies in the warm and Mars in the cold border zones, and Earth is in the golden moderate middle of this biotemperature belt in the planetary system.

The temperature factor logically leads to the question of the presence of water in a biologically usable form; that is, in a liquid state. Water, a prerequisite for the existence of life, serves as the solvent of the various constituents in protoplasma and body fluids; also, like carbon dioxide, water serves as raw material in the photosynthetic production of organic matter and oxygen. Without water, no life. A planet that does not contain water in its biologically usable form could not support life. This is true of the larger planets where water might be present only as ice. The water content in the Martian air is very low and may exist only in the form of vapor and ice crystals. The white polar caps, which melt away in the Martian spring, are probably thin layers of hoarfrost; but there are no lakes and oceans. So, compared with Earth, Mars is a very dry planet with perhaps sufficient moisture to support lower forms of life. The water content in the Venusian atmosphere is still a matter of astronomical dispute. Since Mercury has no atmosphere and a very high temperature, the presence of water is out of the question.

H. Shapley recently termed that area in the planetary system within which liquid water is conceivable on planets, the "liquid water belt"-- a very instructive and appealing term. This is the second characteristic belt in the planetary system.

Still other ecological factors must be considered. One, which we have already touched upon in the water problem, is the chemical composition of the planetary atmosphere--especially the content of oxygen and oxygen compounds such as carbon dioxide.

Oxygen is the key element in the biological energy liberation. The reaction in question is the biological oxidation in the cells. This oxygen reaction results in the breakdown of the foodstuff molecules, down to the smallest possible compounds like water and carbon dioxide. The gain of energy is therefore high. Biological oxidation has made possible the development of organisms to higher stages. This reaction requires a supply of oxygen from the environment.

Another biological reaction for energy liberation, which does not need a supply of free oxygen, is a simple splitting of the molecules. This process does not lead to a breakdown into the smallest possible compounds. The amount of energy gained in this process, also called fermentation, is therefore low, but sufficient for lower organisms. Though molecular oxygen is not required in this process, oxygen is involved insofar as the respective foodstuff molecules contain oxygen intramolecularly.

Carbon dioxide, another biologically important chemical, is--like water--one of the raw materials for the buildup of organic matter in the process of photosynthesis in green vegetation. It is understandable that the possibility of life is always closely associated with the presence of oxygen and carbon dioxide in any environment.

The chemical composition of the planetary atmospheres, especially the presence of oxygen and carbon dioxide, to a large extent depends upon the Sun's radiation--consequently, on the distances of the planets from the Sun. Ultraviolet of solar radiation especially causes considerable changes in their chemistry. The photochemical reactions in question are photodissociations and recombinations.

To understand this entire problem better, we must take a look at the historical evolution of Earth's atmosphere from its primitive stage, the protoatmosphere to the present. This subject matter has been discussed in a most inspiring manner in recently published books of Kuiper and Urey.

The protoatmosphere of Earth some 2.5 billion years ago showed a chemical composition very different from that of the present-day atmosphere. The present atmosphere contains oxygen, oxygen compounds, and nitrogen. Chemically, the present atmosphere is essentially an oxygen atmosphere; it is both oxidized and oxidizing. The protoatmosphere, however, consisted mainly of hydrogen and hydrogen compounds such as methane and ammonia, also of water vapor and helium. It was a reducing and reduced atmosphere and had no oxidizing power. Chemically, the protoatmosphere was essentially a hydrogen atmosphere.

But soon a change set in. According to recent astrophysical theories, the water molecules at the border of the protoatmosphere were split by means of photodissociation into hydrogen and oxygen. The lighter hydrogen escaped into space, and the heavier oxygen remained. With the appearance of this initial oxygen, the protoatmosphere attained oxidizing power. Ammonia was oxidized to free nitrogen and water, and methane to carbon dioxide and water. In this way the atmosphere became more and more oxidized. With the appearance of chlorophyll, more than 1.5 billion years ago, this was accelerated by the process of photosynthesis. The oxygen thus produced oxidized the remaining hydrogen compounds; in addition, an excess of oxygen accumulated to rather large amounts, such as are observed in the present-day atmosphere. This stock of atmospheric free oxygen amounts to 1.2×10^{15} metric tons.

Such was probably the course of events in the evolution of Earth's protoatmosphere to the present-day atmosphere in which we live. Only in an oxygen atmosphere could higher organisms develop; only in such an atmosphere can man exist. If some initial oxygen was already available in the hydrogen atmosphere of the remote past, microorganisms like hydrogen bacteria, methane and ammonia, and iron bacteria could have found a suitable environment. When we consider the present-day atmospheres of the other planets, we find an interesting chemical-parallel to that which we have just discussed.

Astrophysics teaches us that the atmospheres of the outer planets--Pluto, Uranus, Neptune, Saturn, and Jupiter--consist of hydrogen and hydrogen compounds, methane, ammonia, and frozen water. Mars contains oxidized compounds like carbon dioxide, but no free oxygen or only traces of it. Because of its lower gravitational pull--which is only 38% of that of Earth, proto-Mars probably lost its free oxygen into space. Venus has a completely oxidized atmosphere but also, no free oxygen. The higher temperature of proto-Venus, due to its nearness to the Sun, was probably the cause of its oxygen loss. Mercury, the smallest of the planets and the closest to the Sun, could not possibly hold an atmosphere because of its very high temperature and low gravitational pull.

This survey shows, in a most impressive manner, the photochemical effectiveness of solar radiation upon the planetary atmospheres. The atmospheres of the outer planets, in their remote deepfreeze areas, apparently have been only slightly affected by the Sun's radiation. Undoubtedly they may have preserved their gaseous envelopes of the protoatmospheric stage up to the present time. The atmospheres from Mars to Venus, however, have undergone a similar developmental change in their chemistry such as that of Earth.

We recall that in the evolution of Earth's atmosphere, from the far-distant past to the present, a transformation from a hydrogen atmosphere to an oxygen atmosphere took place. Now, considering all the planets in their present state, we note the same chemical sequence when we travel through the planetary system, beginning at the remote distance from the Sun to its immediate neighborhood; namely, a transition from atmospheres containing hydrogen and hydrogen compounds to atmospheres containing oxygen and/or oxygen compounds. Chronologically, the atmospheres of the outer planets may all be about the same age as those of the inner planets, but they are apparently younger with regard to their material metabolism as effected by the Sun's radiation. If this is so, then indeed we recognize in the chemical composition of the planetary atmospheres--in their sequence from the outer to the inner planets--the whole story of the paleontology of Earth's atmosphere.

Now, in this discussion, we are interested mainly in that range of the planetary system where oxygen and/or oxidized compounds are found, as on Mars, Earth, and Venus. Apparently, only within a certain distance from the Sun is radiation strong enough to change the atmospheres to this chemical stage. In the same manner as we speak of a biotemperature belt and a liquid water belt, we may also speak of an oxygen belt in the planetary system. In this belt Earth stands out with an additional high stock of free oxygen; Earth alone was able to accumulate free oxygen and to hold it. It is the oxygen planet par excellence.

This oxygen belt also includes carbon dioxide which, together with water as raw material, makes possible the photosynthetic production of oxygen by green vegetation. Photosynthesis brings up another important ecological factor, namely light. This is the section of the electromagnetic spectrum (from 3500 to 8000 Å) that can be perceived by the eye and within which certain bands are absorbed by the pigment chlorophyll to capture solar energy and convert it into potential chemical energy.

The area beyond Venus, or the trans-Venusian space (Krafft Ehricke), is so highly illuminated as to make a penetration of this region inadvisable, especially if we consider the infrared radiation (heat) and its bearing upon the climatization of the cabin. The trans-Jovian space, too weakly irradiated, will also have its special problem in both respects for the astronaut. Also from the standpoint of life on other planets (astrobiology), solar light is an important ecological factor. This refers essentially to the planet Mars, which has a rather transparent atmosphere. Undoubtedly solar illumination on the surface of Mars is far above the light threshold required for photosynthesis of the terrestrial type. In the distant regions of the outer planets, however, visible radiation becomes weaker and weaker. All this leads us to a photoecological subdivision of the vast space of the solar planetary system. The zone favorable to life and to space operations from the standpoint of light may present a kind of euphotic belt, or biophotic belt, surrounded by a hyperphotic and hypophotic belt.

In summarizing, we observe a zonation in our solar system with regard to life-favoring conditions. We find a euphotic belt, a biotemperature belt, a liquid-water belt, and an atmospheric oxygen belt; and they are all found in about the same distance range from the Sun. They are therefore parts of a general life zone, a zone which we might call the "ecosphere" of the Sun.

Briefly defined, the ecosphere of the Sun is a biological concept. It indicates a zone, surrounding the Sun, in which solar radiation neither exceeds the ecological maximum (therefore, is not biocidal either directly or indirectly through the other ecological factors affected by it) nor falls below the ecological minimum.

This is the zone in which the kind of life now predominant on Earth is conceivable. On the planets in the hydrogen belt, organisms of very low order such as hydrogen, ammonia, methane, and iron bacteria are conceivable; these are the kind that probably populated Earth during its stage as protoplanet some 1.5 to 2 billion years ago, and which we still find today in the pores of the soil and other poorly aerated spaces. However, the low temperature on the outer planets--so to speak, permafrost--excludes the possibility of life in the hydrogen belt. The Sun's radiation beyond the belt of the asteroids apparently has not been effective enough to change the environment on the planets into a biological climate in any respect.

We get a dramatic impression about the extension of the Sun's radiation effectiveness by considering the size of the Sun as seen at the distances of the various planetary orbits. To an observer on Mercury, the solar disk would appear more than twice the size that we see from Earth; on Mars, the Sun would look smaller than the Moon appears to us. At the distance of Jupiter, the Sun's diameter would be only one-fifth of that as seen from Earth. From Pluto the Sun would appear no larger and no brighter than the Evening Star, Venus, does to us on Earth. So we see that in the more remote portions of our planetary system, the role of the Sun as a dominating source of light and heat energy fades into that of a common star. This makes it more understandable as to why the life-supporting planets are conceivable only in a certain zone in the planetary system. (Figure 1)

In our planetary system this ecological zone evidently extends from the area of Venus to beyond Mars, roughly from about 80 to 240 million km (50-150 million mi) from the Sun. The zone itself is therefore about 161 million km (100 million mi) wide. This corresponds to less than 5% of the total reach from the Sun to Pluto. The solar ecosphere is therefore a relatively narrow zone within the planetary area.

The ecological qualities of the planets naturally depend upon some other factors besides the distance of the Sun. The planet's mass is one; its period of rotation, its heat production by radioactivity, and the presence of an atmosphere are others. This has been described by P. Lowell in his book "The Evolution of Worlds" (1910). But the distance of the planets from the Sun may be the predominating factor responsible for their present state of development and their ecological qualities. Using a biological concept like that of the solar ecosphere makes this situation more understandable.

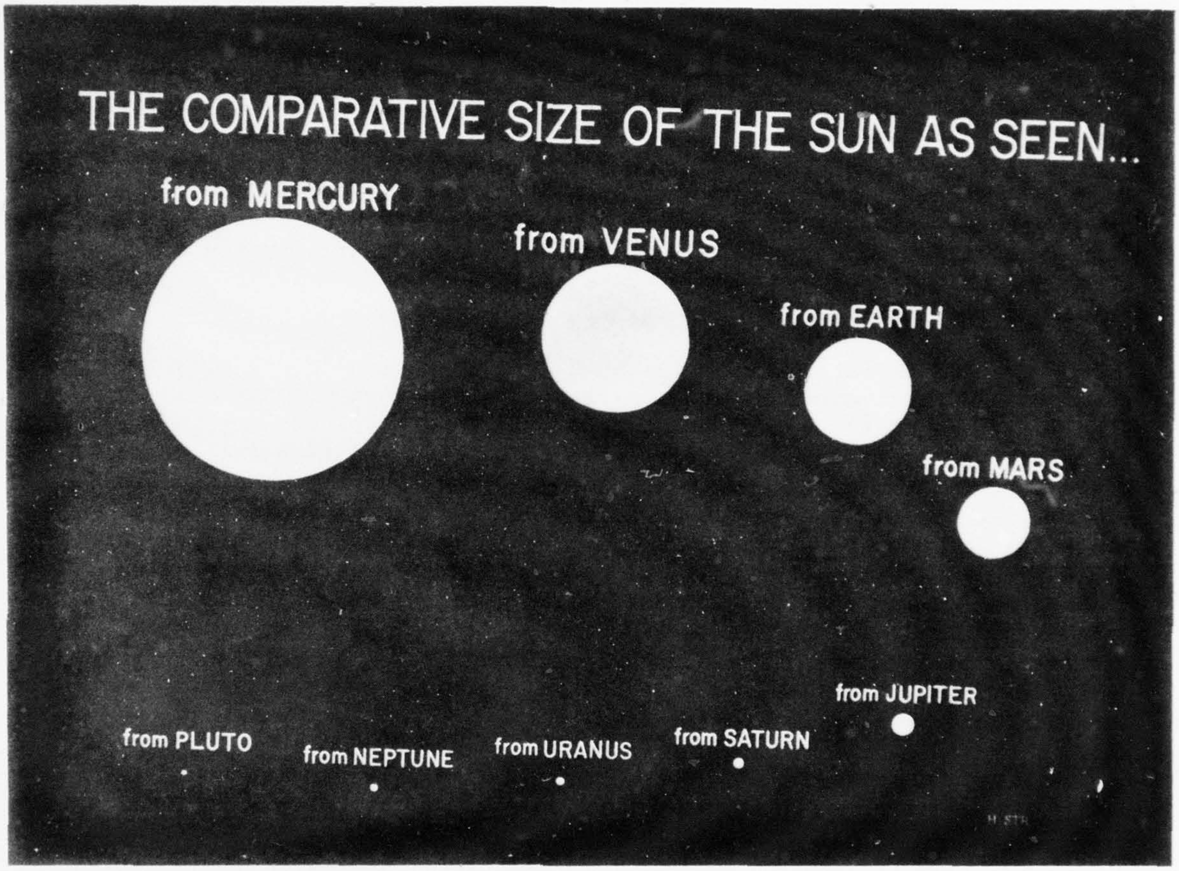

Figure 1. The Sun as seen from various planets.

MECHANORECEPTORS, GRAVIRECEPTORS, ACCELERORECEPTORS

Hubertus Strughold, M.D., Ph.D.

Flying, whether by bird or manmade devices, is a mechanical process. It requires, therefore, not only visual perception and control, but also participation of the mechanical sense organs (mechanoreceptors). Since flying always takes place within the reach of the Earth's gravitational field, these receptors can also be called gravireceptors. In this respect, one thinks primarily of the more centrally located vestibular organ which is encased in bone and is secluded from the surroundings. In contrast, little attention is given to those mechanoreceptors or gravireceptors which are distributed diffusely in the skin, connective tissue, and the muscles of the human body. The physiological importance of these sensory nerves in flying becomes obvious immediately when comparisons are made with animals, particularly with birds. In fact, it is enlightening to revert even to the phylogenesis, to the peripheral mechanoreceptor system of the fish. Swimming, in a sense, is flying in a liquified gas, just as flying can be regarded as swimming in a gaseous liquid. Movement in space, however, is not supported by a gaseous or fluid medium. This makes the comparison especially stimulating.

In its liquid medium the body surface of the fish is subjected to mechanical stimuli, more intensively and extensively than the surface of the human body in its aerial medium. There are many nerve endings in the skin covering of the fish. In addition, the fish has a special apparatus known as the lateral organ, a thick nerve extending along both sides of the body. By means of this peripheral sensory nervous equipment, the fish perceives water currents that pass its body. Pressure waves, and vibrations of low frequency, that occur in the water during concussion, are also perceived by the lateral organ. Solid bodies like rocks are detected at some distance by these mechanoreceptors and located correctly. This faculty is even more highly developed in deep-sea fish. W. Beebe observed in his "bathysphere" that the light intensity decreases rapidly with increasing depths, while the spectrum shifts toward blue-violet. In the Atlantic Ocean, even at a depth of 30 m (or about 100 ft) the light is very dim. It is completely absent at 500 m (1600 ft). In these regions we find fish with luminous organs and telescopic cylindrical eyes. At depths of about 3,000 m (10,000 ft) there are fish with only vestigial eyes. Apart from their chemical sense organs, these deep-sea fish rely almost entirely on the mechanosensory system in their skin to sense the environment. This represents an extreme contrast to the situation that will be experienced by man flying under space conditions, as we shall see later.

A comparative study of the bird's flight is equally interesting. The pinions are organs not only for propulsion and lift but also for sensory control, being sensitive to wind currents. Each quill is surrounded by a highly developed nervous plexus. The subcutaneous connective tissues contain lamillary corpuscles of the type described by Herbst and Vater, and Pacini. They are especially dense near the quills. Numerous so-called muscle spindles are in the flight muscles. Thus, apart from free nerve endings, three types of specialized nerve endings are found. The nerves surrounding the roots of the feathers serve to perceive external mechanical stimuli: air currents and wind resistance; their function is primarily exteroceptive. The other two types provide sensory control for the position, tension, and movement of the flight muscles. By their more or less proprioceptive function, sensory control of movement of the flight number is achieved. With this threefold set of mechanoreceptors, the sea gull can soar gracefully and the falcon can strike the sparrow with precision.

It should be mentioned that among mammals, the bat's fantastic arc of flying must be attributed, in a high degree, to the fine and rich innervation of its patagium.

The peripheral mechanoreceptors generally receive little attention from the standpoint of human flight, and yet they play an important role, especially in small airplanes. In spaceflight, with its gravity-free conditions, a study of their function or the absence of their function is of special interest. In the following, therefore, we shall first describe briefly the anatomy and physiology of the mechanoreceptors in man and then review their functions in flight inside and outside the atmosphere.

PRESSURE SENSE OR TOUCH SENSE

The best-known peripheral mechanical sense is that of touch or pressure of the skin. The sensations produced when the stimulus is continuous are called tactile, pressure, and tickling sensations. When the stimulus is intermittent, the effect is called vibration sensation.

The basket-like nervous plexuses around the hair follicles and the Meissner corpuscles in the skin of the tactile surfaces are the receptor organs for these sensations. They are, therefore, also called pressoreceptors and tangoreceptors. The density of these receptors or their corresponding so-called "pressure points" is about 20 per cm^2 on the skin of the chest, on the back and limbs, and more than 100 on the tactile surfaces of the palms and soles. The pressure points on the hairy surfaces of the skin are arranged in an alternating position, reflecting the phylogenetic development of the hairs from shales. Thus, the pressure sense system covers the entire body with a net of specific nerve endings, totaling more than a half-million.

The specific stimulus for these sensory nerves is not pressure as such, but rather change in pressure. This occurs with each mechanical deformation of the skin by stressing and distressing or increasing and decreasing pressure exerted upon the skin.

The pressure-sense nerves show rapid adaptation; after fractions of a second or for a few seconds, the sensation fades so that slight changes in the pressure or in the deformation at the same skin area will elicit new sensations. Because of this quality, the tangoreceptors are eminently suited for the control of motoric processes. As compared with the vestibular apparatus, the pressure sense is free from disturbing aftereffects.

The reaction time of the pressure sense lies between those of hearing and vision, or at about 160 milliseconds. The latent time of the sensation alone, a part of the reaction time, ranges between 35 and 100 milliseconds, according to Fr. Froelich. The pressure sense, therefore, reacts very rapidly.

The pressorreceptors play an important role in the movements of our limbs and of the whole body, especially in the active limbs. When gripping an object and when walking, we "scan" the surface of the object or that part of the terrain. When one is swimming, the stimulus of the water resistance or pressure evokes sensations in the skin. When one is flying an aircraft, the importance of the pressure sense lies in the sensations produced in the skin area of the seat giving information of the passive movements of the body. Its importance for active movements lies primarily in the control of the plane. In this function and others, the pressure sense is associated with two other sensory mechanisms, the muscle sense and the posture sense.

MUSCLE SENSE

The sensations produced in and by the muscles during passive and active movements are called muscular sensations and tension or tensile sensations. The receptors are the so-called muscle spindles found in all those muscles which fix and move body masses, like those of the limbs. They are not found in the diaphragm nor in the muscles of the vocal cords. The muscle spindles also serve as receptors of the myotatic reflexes (patellar reflex, etc.). The tension sensations of the muscles advise of the resistance which must be overcome when one is moving a limb in the gravitational field or against other dynamic forces. Their receptors are real gravireceptors; they could also be named dynareceptors.

Important characteristics of the muscular sensations are their lack of adaptation and the low relative discrimination threshold (1/70).

POSTURE SENSE

Although the muscle sense indicates the exact muscular tension, it does not indicate the position of the limbs. This function, according to Max von Frey, is performed by the so-called posture sense that is closely related to the postural reflexes as described by R. Magnus, Ubrecht. The receptors are probably the Pacinian corpuscles that are found throughout the connective tissue especially near the muscles. They are presumably stimulated by the pressure exerted by the muscles in their various shapes during different positions and movements of the limbs. In contrast to the pressure sense (and visual and auditory sense), the excitations of the muscle sense and posture sense do not fully trespass the threshold of consciousness; they remain more or less imperceptible.

All three sensory organs, together, form a functional unit concerned with the perception and sensory control of position and movement of body parts. As such, they are integrators in the process of perception of position and movement of the whole body, too.

In this respect the peripheral mechanoreceptors are in a functional union with the centrally located vestibular organ.

SPACE MEDICAL PROBLEMS EN ROUTE TO MARS*

Hubertus Strughold, M.D., Ph.D.

The fast development in astronautics has progressed to the point of programming a manned landing mission to Mars as the first postlunar planetary target. This cosmic venture involves tremendous medical problems covering the entire mission; selection and preparation of the astronauts (or better, areonauts), the interplanetary flight, ecophysiological evaluation of the environment on the planet itself, the human physiological requirements within the Martian station, safe return, and utilization of the experiences for future planning. The accent of the Martian environmental medicine lies, of course, on the conditions encountered on Mars itself. But the interplanetary spaceflight requires just as much medical attention, if not more. In this paper an attempt will be made to identify the medical problems associated with the flight route from Earth to Mars.

We shall not elaborate on the size, configuration, structure, and life-support system of the spaceship, because concepts, material, and equipment of today may be replaced by more advanced ones in 10 years. Instead we shall concentrate on possible hazards from the open, interplanetary space environment and on the duration of the journey, with its medical implications.

The Space Environment from Earth to Mars

The physical environment encountered on any interplanetary flight is by no means uniform--rather it is distinguished by topographical variations and temporal fluctuations with regard to the distribution of matter and energy. We may call the scientific field that explores and charts these environmental differences in space, spatiography (an analogy to planetography, geography, areography, etc.)

Extreme deviations from the normal space environment along the travel route can pose hazards. The environmental factors we have to consider in this respect are: meteoritic matter, solar particle rays, and electromagnetic radiation. In the background, as effective forces behind the topographical distribution of the first two, are the gravitational and magnetic fields respectively.

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The predominant fields of gravitation are the logical ones for a topographical subdivision of the vast plasma ocean of space. Up to 1.5 million km (930,000 mi) from Earth's center, the Mars ship is still in the region of the predominant gravitational attraction (or gravisphere) of the Earth. After crossing this line, which requires escape velocity, the spaceship loses its attachment with Earth's gravity and moves within the gravitational domain of the Sun, until it crosses the border of the Martian gravisphere at 500,000 km (310,000 mi) from Mars. So much about gravitational spatiography in the Earth-to-Mars area.

The gravitational-field forces strongly influence the velocity and direction of particulate matter such as dust and meteoritic material.

Meteoritic Hazards. Two kinds of meteoritic hazards must be considered: Erosion effect and puncture of the ship's wall. The first, caused by micrometeoroids, might affect the windows and communication equipment; preventing this is an engineering problem. Of medical concern are macrometeoroids with puncture capabilities, a possible cause of a cabin leak. At the Earth's orbital distance, the picture of meteoritic hazards in circumterrestrial space looks brighter today than had been expected 15 years ago, according to recordings of satellites such as "Pegasus."

Most meteoroids in the neighborhood of Earth are of cometary origin. According to F. Whipple, they are soft "fluffy stuff," and "ice-dust conglomerate," and neither as frequent nor as violent as had been feared at the beginning of the space age. During the total manned-spaceflight time, now amounting to thousands of hours, no meteoritic incident has occurred; extravehicular activities (E.V.A.) have not met any interference with even micrometeoroids. Moreover, three manned space vehicles have been in orbit during the time when Earth passes yearly through a meteor stream, which are the orbits of disintegrated comets. (Vostok IV - Perseid meteor stream, 12 August 1964; Gemini 7 - Gemenid meteor stream, 13 December 1965; and Gemini 6 and 7 - Ursid meteor stream, 15 December 1965). But stream meteoroids are also occasionally concentrated in the form of a meteor swarm. When Earth passes through such a swarm--which is a rare event--we see the spectacle of a meteor shower such as in 1933 and 1946. All in all, the situation concerning hazards from cometary meteoroids is not alarming at the Earth's solar distance. With increasing solar distance, the situation should become even better because the distribution of these meteoroids becomes less dense and their velocity lower.

In contrast, the number of meteoroids of asteroidal origin might become greater the closer we come to Mars, because of the neighborhood of the belt of asteroids. It has been theorized that some 300 million years ago a planet X between Mars and Jupiter disintegrated into many thousands of asteroids, forming the asteroid belt. It is reasonable to assume that this catastrophic event, or a collision of two smaller planets, led also to a population explosion of smaller pieces of matter; macro- or micrometeoroids. The iron and stony-iron meteorites found on Earth are of asteroidal origin. Since they are of such hard material, their puncture potential must be seriously taken into account. Two characteristics, however, might moderate the puncture potential of these real "bullets from space": first, their velocity close to Mars is lower than at the Earth's solar distance; and second, they might orbit within the ecliptic plane essentially in the same counterclockwise direction as the planets, so that on the way, when close to Mars, the danger for the spaceship comes from one side and on the return from the other side. Head-on collisions might be rare. Be that as it may, a spaceship with destination Mars must be provided with a secondary wall, called meteor bumper (F. Whipple), including self-sealing devices. The hard, very fast meteoroids of galactic origin can be ignored because of their relatively rare occurrence.

Particle Radiation. The radiation dose absorbed in manned orbital flights in circumterrestrial space between 50 degrees north and south latitudes has been less than 1 mrad per hour, or about 15 mrad per day. (The medically permissible maximal dose is 150-200 rads.) Thus, in low orbits, with doses of a little less than 1 mrad per hour, we can look upon the radiation problem with no particular concern. This is different in high orbits; i.e., above 800 km (500 mi), within the Van Allen radiation belts. There we must reckon with up to 5 rads per hour in the inner belt--around 3,000 km (1900 mi), and with 10 mrad per hour in the outer belt--around 18,000 km (11,000 mi). These belts, therefore, are "off limits" for spaceflights of the orbital type. In deep space beyond the magnetosphere, the dose rate received by the occupants of a spaceship might be in the order of 1 rad per month. Such is the particle radiation climate for astronauts, if the absorbing power of the cabin's wall is equivalent to a thickness of 1 cm of steel (T. Alexander and D. Rosen). There are other estimations with a trend to a more optimistic or pessimistic view; at any rate, the intracabin's radiation dose can be minimized by heavier shielding.

If, for the flight to Mars, a circumterrestrial orbit should be chosen as the departure base for the escape operation from Earth's gravitational field, the area below the inner Van Allen belt, due to its low radiation intensity, would be medically the logical one. The penetration of the Van Allen belt, lasting several hours, would lead to an absorption of around 10 to 20 rads--medically acceptable. And, as already mentioned, in interplanetary space the dose rate would be about 1 rad per month. During a journey lasting 8 months, the total dose rate would not exceed much more than 20 rads. A round trip to Mars, then, would result in about 40 rads. So much about the average particle radiation dose we have to reckon with en route to and back from Mars during the time of a quiet Sun.

Concerning a proton outburst after a solar flare, the areonauts, being in communication with the Earth-based solar flare prediction center, should have more than 30 hours "time reserve" to take protective measures. Fortunately, with increasing distance from the Sun, jet streams of protons become less vicious. Travelers en route to Mars should feel increasingly safer about radiation hazards the closer they come to it. In circum-Martian space there is no effective magnetosphere to trap particle rays; therefore, there are no restrictions from a Van Allen-type radiation belt for the selection of the altitude for a parking orbit.

Solar Electromagnetic Radiation. Concerning solar electromagnetic radiation, Mars orbits in the cold border region of the Sun's ecosphere; Venus, in the hot border zone; and Earth, so to speak, in the "golden" middle. (The helioecosphere can be defined as that zone in the solar system in which the electromagnetic radiation intensity is favorable to manned space operations and to life on planets.)

a. Thermal irradiance. At the Earth's mean orbital distance, solar irradiance amounts to 2 cal/(cm^2·min) (terrestrial solar constant). Along the pathway to Mars it decreases to 0.86 cal/cm^2·min) at its mean orbital distance (Table 1). This is of interest in respect to the thermal climate within the spaceship but should cause no bioengineering problems.

b. Solar illuminance at the Earth's mean orbital distance amounts to 140,000 lux (lumens/m^2). On the way to Mars it drops gradually to 60,000 lux (Table 1); we may call this value the Martian illuminance constant. If we allow 20% for loss of light due to reflection and scattering by the windows of the spaceship, there is enough light energy left for the bioregeneration of the ship's artificial atmosphere and waste products by means of photosynthesis.

Looking back to the Sun at the end of the Martian journey reveals its size is smaller--about three-fourths diameter of that seen from Earth. But glancing directly into the Sun for a number of seconds is not advisable because this might cause a retinal burn. It is not ultraviolet but heat radiation that causes such a retinal injury, which is the same as eclipse blindness (often occurring when people observe a solar eclipse through an insufficiently smoked glass). But even a brief glance into the Sun affects the dark adaptation of the eye, and this might be one of the reasons that some astronauts reported that they could not see the stars.

On Earth we are exposed to a cycle of light and darkness caused by the Earth's rotation, lasting 24 hours. In circumterrestrial orbital flight, below the Van Allen belt, this cycle is reduced to 90-120 minutes. On a trip to Mars there is no such cycle; instead, there is, so to speak, day and night at the same time: the Sun as the symbol of the day and the velvet black sky as the symbol of night. But the areonauts require an alternation of sleep and wakefulness, dictated by their "physiological clock" which is adapted to the Earth's day-night cycle. They must program their sleep-activity cycle in the terrestrial-duration pattern and in shifts within their team. After arrival on Mars there should be no problem in this respect, since its rotational period is only 37 minutes longer than that of Earth.

Duration of the Flight

As soon as the areonauts come nearer than 300,000 km (186,000 mi) to Mars, they have a closer look at its surface with the unaided eye than Earth-based observers have with the best telescope. They are now actually already within the Martian gravitational "territory" which they entered at a distance of 500,000 km (310,000 mi), leaving behind the vast interplanetary "ocean" of solar plasmatic wind.

Summary

Crossing the interplanetary ocean takes about 8 months if an "economic" (minimum energy) trajectory is chosen. This is the simplest way for unmanned, automated planetary probes, such as the Surveyor, Mariner, Lunic, etc.

Is such a duration also acceptable for a manned Mars mission? To get a realistic judgment about this question, we must consider the life of the mission crew, a team of perhaps six or more, in its whole complexity. They live in a cramped, closed ecological world with is own economy and autonomy.

Their activities--in addition to the ship's power control, navigation, exploration of the cosmic sky, and radio communication with the Mars Mission Control Center on Earth--include control of the life-support system and of contaminants, hygiene, and "household" duties, etc. Weightlessness complicates some of these activities, others are facilitated.

The areonauts, after several days of flight, should be in a state of "relatively stable adaptation to weightlessness," as can be concluded from the experiences in orbital flight. The Gemini record flights indicate that under comfortable intracabin conditions, and applying an appropriate sleep regimen, man can probably endure spaceflight in the order of months. Artificial gravity seems not to be required. Nevertheless, it is medically advisable, if not even a requirement, to base a flight plan to Mars on a high-energy trajectory to shorten the minimum-energy trajectory duration of about 8 months to 30% to 20% of this time; this can be achieved by novel methods of propulsion.

In addition to the man-machine-cabin environment complex, the external space-environmental conditions must also be taken into account. A shorter time reduces the possibility of meteoritic incidents and the radiation hazards of an encounter with solar flares.

In brief, minimum time and optimum comfort is the medical prescription to achieve maximum success of the planetary landing mission. It should be added that, particularly with regard to the psychologic and physiologic aspects, astronauts with week-long experiences in circumterrestrial orbital flight and physicians who have controlled these flights must have a decisive voice. The studies concerning hematological changes, vascular tone, mineral metabolism of the muscles and bones, and the countermeasures carried out so far and those planned in the future will weigh heavily concerning tolerance of long-duration flights. With cautious extrapolation of what has been learned so far, the medical answer concerning the prospects of a flight to Mars is positive and optimistic if trajectory time is reduced.

TABLE 1. SOLAR ELECTROMAGNETIC RADIATION FROM EARTH TO MARS*

	Earth					Mars
Mean solar distance ($\times 10^6$ km)	149.6	160	180	200	220	227.9
Thermal irradiance cal/($cm^2 \cdot min$)	2	1.75	1.38	1.12	0.92	0.86
Illuminance ($\times 10^3$ lux)	140	122	96.6	78.2	64.6	60.3
Intensity factor	1	0.87	0.69	0.56	0.46	0.43

*Ref: H. Strughold and O. L. Ritter. Solar irradiance from Mercury to Pluto. Aerosp Med 31:127 (1960).

GRAVISPHERE, GRAVIPAUSE: ASTRONAUTICAL ASPECT*

Hubertus Strughold, M.D., Ph.D., and O. L. Ritter, Ph.D.

INTRODUCTION

The environment on Earth is conventionally subdivided into the following components, or spheres:

(1) the lithosphere (continents and islands),

(2) the hydrosphere (oceans, lakes, and rivers),

(3) the atmosphere, and

(4) the biosphere (regions of the above-mentioned three environmental spheres, which are populated by living beings; also used to denote the whole living world).

The Space Age has brought into focus two other environmental components:

(5) the magnetic field, with emphasis upon the magnetosphere--the background of the Van Allen radiation belts, and

(6) the gravitational fields of Earth and of the other celestial bodies of the solar system, particularly the regions of predominant gravitational attraction.

In all kinds of space operations--such as unmanned satellites; manned orbiting spacecraft; and lunar, planetary, and interplanetary probes--the gravitational situation plays a decisive role. In the following paragraphs this environmental factor will be discussed in some detail.

In astronomy and astrophysics the gravitational forces are basic in considering the mutual attraction between celestial bodies, orbital perturbations, and tidal effects. In astronautics we are especially interested in regions where the gravitational force of one celestial body prevails over those of other neighboring celestial bodies. In the

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astronautical literature these regions are known as "the spheres of predominant gravitational influence" (1). Other names used are "activity spheres" and "spheres of gravitational activity." For these spatial units we suggested the term "gravisphere" several years ago (2, 3).

In the "Planetary Gravispheres" article (3), a distinction was made between an inner and an outer gravisphere. The inner gravisphere refers to that region within which the gravitational attraction of a planet or moon is able to hold a satellite in orbit; therefore, we can call it also "potential satellite sphere." It might be advisable to restrict the term "gravisphere" to this gravitational region; namely, to the potential satellite sphere. Actually the satellites or moons of all planets are found in a relatively narrow zone close to the primary; this zone represents the actual satellite sphere within the potential satellite sphere (gravisphere). There is also a lower limit for natural large satellites--the Roche's Limit, 2.44 radii from a planet's center. Gravitational tide effects at this near distance prevent matter accumulating to form a larger satellite.

The outer gravisphere, the region beyond the potential satellite sphere, the gravitational force of a celestial body is no longer dominant but is still strong enough to influence noticeably the trajectory and velocity of a space vehicle. For this region the term "gravipause" might be appropriate in analogy to the term "magnetopause." But most important for astronautics is the inner gravisphere, the potential satellite sphere, and this is the region we have in mind when in the following we speak briefly of gravisphere.

THE GRAVISPHERES OF THE EARTH AND THE MOON

The gravisphere of the Earth, or its potential satellite sphere, reaches as far as 1.5 million km (about 1 million mi) from the Earth's center; this is 4 times farther away than the Moon. Beyond this distance the gravitational field of the Sun is predominant, and a space vehicle can become a satellite of the Sun; but up to several million kilometers, the vehicle is still in the Earth's outer gravisphere, or gravipause.

The Earth's actual gravisphere (satellite sphere) is determined by the distance of the Moon. So far, no smaller satellites of the Earth have been detected. Nevertheless, the Earth's gravisphere, as any other gravisphere, must be considered as a collector of dust and meteoritic matter. In this respect, it is interesting to note that the Earth might be surrounded by a dust belt, as recently reported in the literature (4, 5, 6).

At a mean orbital distance of 384,000 km the Moon moves around the Earth and has its own gravisphere, which extends to approximately 60,000 km (36,000 mi) from its center (cislunar: 58,000 km; translunar:

64,000 km). When a space vehicle crosses this Earth-Moon "gravitational divide," it can, if properly guided in direction and controlled in velocity, become a satellite or orbiter of the Moon.

It might be mentioned here that in the earlier literature there was some confusion of the extent of the gravisphere with the distance from Earth of a point variously called the neutral, abaric, or equigravic point, and with the Lagrangean points. A discussion of these matters is found in reference 7.

THE GRAVISPHERES OF THE OTHER PLANETS

The extensions of the gravispheres of the other planets grow in size as a function of the planet's mass and its distance from the Sun, because solar gravity decreases with increasing distance. Their radii are compiled, together with those of the Earth and its Moon, in Table 1.

TABLE 1. RADII OF THE PLANETARY GRAVISPHERES

Mercury	0.22	million	km
Venus	1.0	"	"
Earth	1.5	"	"
Mars	0.5	"	"
Jupiter	53	"	"
Saturn	65	"	"
Uranus	70	"	"
Neptune	116	"	"
Pluto	57	"	"
Moon	0.060	"	"

The extension of the gravisphere of each planet is a little smaller in the Sunward direction than in the opposite direction, but for all practical purposes these differences can be neglected. Neptune, with a surface gravity of 1.12 g, has the largest gravisphere (116 million km in radius). It is more than twice as large in radius as the Jovian gravisphere (53 million km), despite the much greater mass and gravity of Jupiter (2.64 g); the reason: the Sun's gravitational energy at Neptune's mean orbital distance is much lower than that at Jupiter's solar distance. For the same reason, Pluto's gravisphere is 100 times larger than that of Mercury although both planets have about the same size. In fact, all the gravispheres of the outer planets are of about the same or larger size than a volume with a radius equivalent to the distance from the Sun to Mercury.

The gravisphere of the Sun extends about halfway to the nearest stars. If Pluto is the last planet in the solar system, then the actual satellite sphere (or better, planetosphere) of the Sun ends there. But the trans-Plutonian region of the solar gravisphere, or the Sun's potential satellite sphere, might be the place of origin of comets. Millions of these giant balls of "ice and dirt" (8) may accumulate and remain there, forming a "comet cloud" until some disturbance occasionally injects one of them into an elliptic orbit around the Sun.

All in all, in terms of size the first-order gravisphere in our solar system is, of course, the gravitational empire of the Sun, which blends, far beyond Pluto, with the gravitational "no man's land" between the stars. Second-order gravispheres, then, can be considered to be those of the planets; and third-order gravispheres, those of the moons--the smallest gravitational "territories" in our solar system.

In conclusion, the concept of the gravisphere completes the picture of the planets' environmental profile. Furthermore, it provides the dynamographic basis for a "geographic" subdivision of space, or spatiography, useful for the identification of and navigation in orbital flights and escape-velocity operations.

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LIFE ON MARS IN VIEW OF RECENT DISCOVERIES
*OF EARTH-BASED AND SPACE-BOUND ASTRONOMY**

Hubertus Strughold, M.D., Ph.D.

The question of life outside Earth has attracted the interest of philosophers, astronomers, and biologists for several centuries. The science that studies this question is now called astrobiology and cosmobiology. These studies usually refer to the kind of life as we know it on Earth, which is based on carbon as the fundamental structure atom of the molecules and, therefore, is called carbon biology. Suggestions have been made about different kinds of life based on other fundamental atoms; these must be considered at present as pure speculations. But if we consider resistance and adaptability with reference to different environmental conditions, we find some indications for the possibility of terrestrial-type life existing on neighboring celestial bodies. This has found strong support by experiments in planetary environmental chambers in which other planetary environments are simulated.

In the center of the astrobiological discussions has always been the planet Mars, due to its exceptionally good surface visibility. There are three kinds of areas on the Martian surface clearly recognizable in the telescope; namely, reddish areas which represent about two-thirds of the total surface; large dark regions, dark spots, and dark linear markings; and white caps at the northern or southern poles, depending on the winter season. The dark areas are considered as the regions in which some kind of plant life might exist, as suggested by their seasonal color changes from dark to bluish-green, to brown, and to dark again.

But, in addition to the visible solid surface, we must consider also the possible occurrence of water; the existence of an atmosphere, of a magnetic field; and the kind and intensity of radiation. Our knowledge in this respect has been gained essentially by theoretical considerations, by visual observations, and by spectrographic studies in ground-based astronomy.

But on July 14, 1965, a revolutionary success of space-bound astronomy was achieved with the historic fly-by mission of the planetary probe Mariner IV at a distance of 6,118 miles from Mars. The photographs taken by Mariner IV showed that Mars is covered by a great

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number of craters. It was also found that the atmosphere is much thinner than had been earlier believed; furthermore, Mars has a very weak magnetic field. Many, therefore, considered the red planet to be more Moonlike than Earthlike, and consequently some doubts were expressed about the possibility of life on Mars. But the picture is not so bad as it initially might have appeared.

The new discoveries are, of course, of vital interest for a manned expedition to Mars; in other words, for Mars medicine. But in the following, I shall confine myself to Mars biology.

Beginning with the relief of the Martian surface, the general opinion has been that the reddish areas are highlands and the dark regions are lowlands. This seems to be confirmed by the radio occultation measurements of Mariner IV, according to which a certain reddish area, named Electris, is 5 km higher than a dark region called Mare Acidalium.

The dark areas, according to most observers, show seasonal color changes from dark to bluish-green, to yellow-gold, to brown, and back to dark, which is interpreted as an indication of green vegetation on Mars. They appear always to be dark gray to some observers, but this can be accepted only if they have normal color vision, confirmed by an ophthalmologist.

The bluish-green color is also considered to be a visual color phenomenon occurring against the ochre-red surroundings. Visual contrast effects certainly occur, especially if the areas are small; but the bluish-green coloration of large areas such as the Syrtis Major is in all probability real. This is supported by the observation of Clyde Tombaugh, discoverer of the planet Pluto, according to which certain areas occasionally look dark when others look green, despite the fact that both are surrounded by reddish areas. The final answer in this color dispute might come from color photographs made by future fly-by probes. But being green, or not green, is not decisive for life "to be or not to be" on Mars.

Fifty years ago, S. Arrhenius in Sweden advanced the theory that the dark areas are salt beds of dried-out oceans, which respond to changes in atmospheric humidity, and concluded that "Mars is indubitably a dead world." But in the Dead Sea, in Palestine, which is an extraordinarily salty medium, numerous species of microorganiams (algae and bacteria, etc.) flourish abundantly. The Dead Sea, therefore, is not so dead at all, as it was believed. And the Red Planet, Mars, might not be so dead, as well.

The dark areas have also been explained as being deposits of volcanic ash blown over them by the prevailing winds, and the color changes have been attributed to reactions to seasonal variations in humidity or to radiation. This, of course, does not exclude the possibility of life, because terrestrial bacteria, lichens, and mosses can grow on lava. Actually, bacteria can grow on practically any material, even in oil wells and in jet fuel containers, as indicated by the new bacteriology branch, petroleum bacteriology.

Occasionally there are heavy dust storms on Mars. After such storms the whole planet appears reddish, as was the case in 1956. But several weeks after such events, the dark areas reappear. This can be explained only by the assumption that some of the dark soil components must have regenerative power, which again points to biologic material.

Where there are dust storms, there must be an atmosphere as a dynamic medium to carry the dust. The earlier estimations of the atmospheric pressure at ground level on Mars, based on spectrographic studies, ranged from 80 to 10 mbar. The occultation experiment of Mariner IV suggests a pressure of 10 to 5 mbar. Could microorganisms survive such low pressure? Recent experiments in space environmental simulators and in containers carried outside a spacecraft have shown that bacteria, particularly spores, are resistant even to a vacuum.

Oxygen so far has not been detected in the Martian atmosphere. This does not exclude life, as proven by the occurrence of various types of anaerobic bacteria on Earth. Life without oxygen, called anoxybiosis, might be the Martian way of life; however, microorganisms might exist there capable of producing their own oxygen by means of some kind of photosynthesis. If there are multicellular organisms with this capability, they might be able to store the self-produced oxygen in intercellular air spaces of the kind found in terrestrial leaf plants and in lichens and mosses. Photosynthesis requires carbon dioxide and water as raw material.

Recent spectroscopic studies indicate that carbon dioxide pressure in the Martian air might amount to 3 mbar; i.e., 10 times as high as on Earth. This would be an advantage for the growth of green vegetation, since carbon dioxide in this pressure range increases photosynthesis. Beyond 29 mbar it has an inhibiting effect upon this process.

Water vapor has been detected in the Martian atmosphere, but it is extremely scarce, only about 0.001 of the mean humidity of the terrestrial atmosphere. More important than the atmospheric humidity is that of the soil. If the barometric pressure is below 7.5 mbar, this is below the "triple point" of water; i.e., water can exist only in the state of vapor and ice. But in the lowlands of Mars the air pressure might be around 10 mbar; in this case it could occur also in the liquid state in the soil. The "wave of darkening" moving from pole to pole in spring is an indication of soil moistening. Water, of course, is decisive for the existence of life. But some terrestrial microorganisms can survive long periods of complete desiccation. Seasonal periods of extreme dryness of the Martian surface would not destroy them. The water situation on Mars is certainly severe but not to the extent that it is prohibitive to life of the low-level terrestrial type. Moreover, there might be subsurface ice layers which could increase the soil's humidity locally. They are considered to be remnants of ancient oceans, now covered by some 100-m thick layer of solidified dust. This theory, advanced in 1910 by Baumann in Zurich, later somewhat forgotten but recently revived, is very attractive if combined with two other concepts.

In 1937, P. A. M. Dirac, advanced the hypothesis that the gravitational constant has decreased slightly during the lifetime of the solar system and continues to decrease. This has led to an expansion of the Earth, causing "tension cracks" or fissures on land and at the bottom of oceans--as recently described by R. H. Dicke and P. Jordan, who both confirmed Dirac's theory which was first generally not accepted. The splitting of the two giant original supercontinents, Gondwanaland and Laurasia, about 1 billion years ago into several secondary continents, now widely separated by "continental drift" (A. Wegener), is attributed to this gravitational phenomenon.

It is logical to assume that on Mars this gravitational decrease has caused similar effects; namely, volume expansion and tension cracks after Mars had cooled off at the end of its protoplanetary phase and had reached a temperature equilibrium. And meteoritic impacts, in addition to volcanic Marsquakes, could have triggered fissures of tremendous lengths, particularly in a crust of different layers, including a subsurface ice layer. This threefold environmental condition (subsurface ice layer, planetary volume expansion with subsequent tension cracks due to gravitational decrease, and meteoritic impacts) might well have been the mechanism behind the scene of the dark spots (oases) and the dark linear markings (canali) radiating from the dark spots over enormous distances. A subsurface ice table, or hydrocryosphere, would increase the humidity locally; i.e., in and around the meteoritic impact craters and in and along the fissures, making them ecologically more suitable for the growth of vegetation. Actually, it might be the soil's humidity and vegetation that made these Martian surface features visible to Earth-based optical astronomy in the first place. To conclude this water dispute, the existence of native life on Mars would not be conceivable if there had not been ancient open waters for its origin.

The Martian surface temperature is ecologically adequate in summer for about 5 hours each day. It can reach a maximum of +30°C, but at all other times it remains below the freezing point of water; it drops to a minimum of -60°C and lower, a condition which appears particularly prohibitive to life. But we know of bacteria and spores that survive temperatures close to absolute zero; furthermore, it has been found recently that the terrestrial bacterium (*Aerobacter aerogenes*) survives when experimentally exposed to a diurnal freeze-thaw cycle. Protection against frost could also be provided if the Martian plants were able to produce some kind of antifreeze. Generally, then, a biology on

Mars during its cold nights turns always into a low-temperature one, or into cryobiology. However, locally there might be exceptions in the form of permawarm spots on the surface, similar to those on Earth (for instance, in Alaska, Wyoming, Iceland, and New Zealand). There is no reason in terms of planetary analogy why similar permawarm spots should not exist on Mars, possibly above dormant volcanos; they would not have the low night temperatures, and therefore would have a higher ecological potential. Scanning the surface with heat sensors by future automated Martian orbiters may answer this question.

The low density of a 10-mbar pressure atmosphere might not provide effective protection from harmful solar ultraviolet and X-rays, it is argued. However, the intensity of solar irradiance at Mars' distance from the Sun is less than half of that at Earth's solar distance; furthermore, a certain amount of these rays is certainly absorbed within the atmosphere. It is, of course, well known that ultraviolet rays, particularly in the range from 2500 to 2800 Å, are indeed very destructive to most terrestrial microorganisms. For this reason they are used for sterilization of food and to prevent interplanetary contamination by lunar and planetary probes. But there are various degrees of resistance to ultraviolet and X-rays; certain microorganisms are even stimulated in growth when exposed to low-intensity ultraviolet and X-rays. Also, some microorganisms, plants, and animals are less susceptible to ionizing radiation under hypoxic and hypothermal conditions. This is particularly interesting with regard to Mars with its oxygen-free atmosphere and low temperature.

Finally, energetic particle rays of solar and galactic origin are considered as possible adverse factors to life on Mars because they can reach its atmosphere unhindered by a magnetospheric shield. But because of the greater distance from the Sun, the influx of particle rays of solar origin is certainly lower; and the so-called microenvironment provided by caves, craters, and fissures might offer effective protection.

Considering all of the physical, chemical, and biological factors and their interrelations, and particularly the adaptability of life to adverse conditions, as found in free nature and tested experimentally in Mars chambers, we must come to the conclusion that the occurrence of life on Mars, on a low-level, is more in the realm of probability than of possibility. Some of the findings of Mariner IV and of modern Earth-based astronomy are more hostile to life, but others are more favorable. In the years ahead life-detecting instruments on-board unmanned landers will be sent to Mars for acquisition and analysis of soil samples and for transmitting the data back to Earth; but the final and more detailed answer concerning a Martian biosphere might come from a manned Mars-landing mission. If the answer is that no life exists on Mars and never has, this would give the explorers a unique opportunity to study the chemistry of a virgin planet of the terrestrial group. If the answer is yes, then we would be interested to know if the Martian life is similar to that on Earth (based on carbon biology) or of a completely different kind unknown to us. Be that as it may, the discovery of life outside Earth would not be the news of the year, nor of the century, nor the millenneum--it would be THE NEWS in the recorded history of mankind.

OUT OF SPACE--ADVANCES FOR MEDICINE

Hubertus Strughold, M.D., Ph.D.

Medicine--the science and art of preserving and restoring health--was in existence in a primitive form at the time of the caveman. During the Greek and Roman era it developed into a rather sophisticated art, based on philosophical speculations and anatomical observations which dominated medical thinking throughout the Middle Ages. But with the invention of the microscope in the 17th century, the discovery of the atomic elements and their significance as "bioelements," the discovery of electricity and X-rays, the scientific study of the biological effects of chemical compounds (drugs, antibiotics, etc.), and the development of anesthesia, it has become a highly scientific art with numerous specialties. Modern technology and modern means of travel added new branches: industrial medicine and environmental medicine.

One of the environmental medical disciplines is the field of aviation medicine, or aeromedicine. It encompasses certain medical problems associated with higher atmospheric altitudes, speed, orientation, causes of crashes, etc. With the development of an atmosphere-independent propulsion device--the rocket, man's travel beyond the atmosphere became possible and a new branch of medicine came into being, known as space medicine or cosmic medicine. It is actually an extension of aeromedicine along the vertical frontier. Whereas aeromedicine is concerned with the medical problems involved in atmospheric flight, space medicine is devoted to the life and performance of the astronaut in spaceflight, and with his survival on other celestial bodies such as the Moon and Mars. Since some of the problems in these two areas overlap, the term "aerospace medicine" has also come into use.

There is one important point which cannot be overemphasized: the aeromedical and space medical efforts not only serve their specific purpose--that of the preservation of life in atmospheric and spaceflight, they both have had, and will have, a tremendous impact upon medicine in general and its various disciplines. There are numerous by-products--or better, bonus effects--from which the entire field of medicine will benefit. These benefits are twofold: first, they will increase our knowledge of the physiological functions of the human body in their relation to our natural physical environment on Earth; and second, they will have a definite influence upon the future development of medical methods, concepts, and terminology in research, teaching, and practice. In the following paragraphs these beneficial by-products will be discussed more in detail, with emphasis on those derived from space medicine or bioastronautics.

To begin with, there is the environmental factor--gravity. This is the force responsible for our weight and is expressed as 1 g--the gravity on Earth's surface. In medical training this factor is usually treated as a self-evident force, everywhere, ever-present, and constant, and therefore not considered as a particularly exciting component in our natural environment. It becomes conspicuous in human life only when the organism is not yet strong enough to cope with it, as in the first few years of infancy--after the easy months in the uterus capsule, or when the organism has become too weak, as in certain diseases and old age. Actually, there are certain diseases and abnormalities which are caused or aggravated by the constant gravitational pull; to mention only one--varicose veins.

Modern means of transportation can change this gravitational constancy. In travel by ship on a rough sea we are exposed to periodic variations around the geogravitational norm of 1 g, occasionally leading to seasickness. In travel by air in adverse flying conditions, similar g oscillations may result in airsickness. Both of these types of motion sickness are now well understood and are, to a high degree, therapeutically controllable. From this, our knowledge of causes of nausea in general and the study of therapeutical means of treatment have benefitted. In certain military flight maneuvers (turn, pull-out, ejection), increased g values up to about 4 g's are experienced. In spaceflight, increased g loads of 7 to 10 g's occur for several minutes during launching and atmospheric reentry, causing enormously increased weight. Experiments on large centrifuges and rocket-powered sleds have provided the medical know-how to successfully overcome these gravitational stresses. This knowledge has also proved to be of great value in the analysis of mechanical injuries and for protection in traffic accidents on Earth's surface. It is perhaps not generally known that the use of safety seat belts in automobiles, now used by millions of people throughout the world and which have saved many lives, received a tremendous impetus by experiments made on rocket-propelled sleds by Colonel J. P. Stapp, USAF, MC. Anti-g suits are worn by pilots of high-performance jet aircraft and in space vehicles. They exert mechanical pressure upon the lower part of the body, especially the legs, to counteract the increased hydrostatic pressure. Modified partial-pressure suits are worn today by patients having weak circulation in the legs, which makes life in the vertical position easier for them.

But even more than increased gravity, subgravity and zero-gravity, resulting in decreased weight and weightlessness that occur during the greater part of any spaceflight trajectory between launching and atmospheric reentry, have really made the problem of gravity an intriguing one. We must keep in mind that the occurrence of weightlessness in spaceflight is not a function of the distance from the Earth; rather, it is the result of a balance between Earth's gravitational attraction and the inertial forces of the moving vehicle and its occupants. It is dynamic weightlessness. This occurrence of dynamically nullified weight shows us that mass and weight of a material body are not the same. Mass is an intrinsic property of matter representing the sum of all atomic particles that compose the material; weight is an extrinsic property of matter, depending on external forces. In actual spaceflight this property of matter (weight) is absent, and this is for us a strange and most exotic condition.

The tolerability of this condition--zero g--is again of interest for both space medicine and medicine in general. Thousands of so-called parabolic flight maneuvers in jet planes, in which the state of weightlessness can be produced for 1 or 2 minutes, have shown that most of the fliers were in no way affected. Also, monkeys and dogs in suborbital rocket flights which lasted a few minutes and several Russian dogs and the American monkey Enos in orbital flight, were not disturbed by weightlessness. The same has been true during suborbital flights of American astronauts A. Shepard and V. Grissom and during orbital flights of astronauts J. Glenn, S. Carpenter, and W. Schirra, and the Russian cosmonauts Y. Gagarin, A. Nikolayev, and P. Popovich. The Russian cosmonaut G. Titov, however, became nauseated after 3 hours of orbital flight.

What general medical knowledge do we gain from these experiments and experiences? First, the study of performance and orientation under weightless conditions leads to a better understanding of the function of the vestibular apparatus in the inner ear and of the peripheral mechanoreceptors, such as the touch sense of the skin, and the muscle sense. The otolith organ is gravity dependent; the other mechanoreceptors are not. This explains why manual performance of the astronauts is not impaired, as demonstrated in the flights of Glenn, Carpenter, and Schirra. By eliminating gravity, as in spaceflight, and also by comparing this situation with that of submersion in water, we learn more about the specific functions of all these mechanical sense organs, gravireceptors, and gravireflexes involved in the position and movement of our body and limbs under the normal gravitational conditions on the solid ground. We also obtain a better insight into abnormal neurological and muscular reactions in pathological cases.

The study of certain vegetative functions under the condition of weightlessness is no less revealing. Examining the circulatory system with the hydrostatic pressure removed, because the blood has no weight, contributes to our knowledge in the field of hemodynamics. Under this condition we can expect a temporary increase of blood pressure in the upper part of the body and a decrease in the lower part. The same will be true to a lesser degree under the reduced gravity of the Moon and Mars, with a person in an upright position. This is understandable because, due to a lower or zero hydrostatic pressure, the blood pressure is more evenly distributed over the whole circulatory system, similarly as observed on Earth in a horizontal position. A comparison of the topographical blood pressure pattern as it can be expected on Mars, on the Moon, and under zero-gravity conditions is very instructive and leads to a better understanding of the hemodynamics on Earth.

It can also be expected that weightlessness for longer periods of time leads to a general weakness of the muscles and of the circulatory system, as has been observed in submersion experiments in water tanks. To prevent such hypodynamic effects, methods for exercise have been developed. The equipment for such space calisthenics which, due to the cramped area in a space vehicle, must be of the isometric type, is certainly also very useful for bedridden patients who cannot move around and perform exercises in the isotonic fashion. (Examples of isotonic exercise are walking, running, and dancing, which involves changes in the length of the muscles but not too great a change in their tonus; isometric exercise is muscular action with increased tonus, as, for instance, counteraction against elastic forces.)

For another example, let us assume that a baby were born either under zero-g conditions or under the subgravity condition of the Moon. A speculation about its physical development is worthwhile. A subgravity Moon baby of terrestrial heritance, after several years brought to the Earth with its gravity 6 times that of the Moon, would probably first have to learn to swim, and later to walk, following in a sense the developmental pattern in paleontology--the evolution from sea life to land life. A similar course in the development of movement capability is actually observed in polio-inflicted babies.

It has been observed that under weightless conditions, the urge for voiding is somewhat less pronounced. From this it can be concluded that the most sensitive reflexogenic zone for this body function is primarily located at the bottom of the bladder. It is therefore understandable to assume that patients, especially after operations, should be brought to a vertical position to take advantage of the stimulating effect of gravitation.

So much for this dynamic gravitational-force factor: its constancy in our natural environment; possible periodic variations in air and sea travel; its increased amount in the active, and its absence in the passive, phase of the spaceflight trajectory. The norm for man is 1 g--Earth's gravity; it has been this during the entire history of mankind. But spaceflight has broadened its spectrum from the baseline of 1 g up to 10 g and down to zero g. From this we have learned that gravity can be beneficial, and also detrimental, to the health of man. We can now better understand both sides of the picture by studying what occurs when it is completely absent, as in the weightless phase of spaceflight.

It might be noteworthy to mention at this point that so far we do not find the word "weightlessness" in medical textbooks; and yet in a free fall, in the initial phase of a descending elevator, and in a ship at the crest of a wave, weightlessness or decreased weight is experienced for a few seconds. It had been overlooked until space medicine brought it to our attention, but in the future, weightlessness will be used in medical teaching as a contrast to the normal gravitational condition.

It might be interesting to speculate on what the physical structure of man and his behavior would be if Earth had a different gravity; for instance, that of Mars which is 0.38 g, or Jupiter's 2.64 g. Such an "out of space" perspective would reveal that the natural movement of man, and the artificial means of transportation, would then be rather different. But a different gravity on Earth would also influence other physical environmental factors vital to man; in the first place, the atmosphere--its pressure and chemical composition.

We have learned a great deal about Earth's atmosphere from outer space--its life-supporting and life-protecting functions--by comparing our natural surroundings with an environment that is distinguished by complete absence of atmospheric material. Space medicine, therefore, has to provide the astronaut with an artificial atmosphere and with all nutritional and sanitary necessities when he is in a sealed cabin, surrounded by a nearly perfect vacuum, thousands or even millions of miles away from his home planet. This is a task unique in the history of medicine. But space medicine has developed methods to keep oxygen, carbon dioxide, humidity, and the temperature within comfortable limits. We cannot go into detail concerning the life-support system of the astronaut's little Earth, or "terrella"; instead, I should like to point out what we can learn from these endeavors for the benefit of medicine and biology in general.

First, we now have a better knowledge of the maximum permissible oxygen pressure--about 350 mm Hg. For longer periods of time this is in the order of 300 mm Hg; i.e., about twice the pressure of O_2 in the atmosphere at sea level. Above this level oxygen becomes toxic after several days. This is important for patients kept under an oxygen tent. And carbon dioxide, which is exhaled in respiration, should not exceed 1%, or about 10 mm Hg pressure. At higher levels it leads to suffocation.

In an oxygen-rich atmosphere we have to reckon with the increased possibility of fire. For spacecabin-simulator experiments, a method has been developed, based on gas chromatography, to detect gases arising from smoldering material, hours before a fire would break out. Its usefulness in buildings (particularly skyscrapers) is obvious--to detect fires in advance, for the safety of the occupants.

For the purpose of logistics in spacecabins, methods have been developed to regain the oxygen from the exhaled carbon dioxide and water vapor. For short durations (over a period of weeks), physiochemical means are used for recycling respiratory gases. In extended space operations (lasting many months), especially on extraterrestrial bases such as a Moon base, regeneration of all the vital requirements by biological methods, similar to those we observe in free nature, becomes a necessity. Here the process of photosynthesis, found in all green plants, enters the picture of medical research. In this way we are learning to reproduce the properties of the "macroclimate" on Earth on a "microclimatic" scale, which might be useful in many ways; for instance, disaster shelters. Much has also been learned about atmospheric recycling from "out of the deep sea" through submarine medicine.

The same is true concerning the problem of the physiological day-night cycle. After a number of hours of activity, man requires rest and sleep or the restoration of energy, and this rest-and-activity cycle is usually synchronized with the physical day-night cycle. To keep this physiological rest-and-activity cycle functioning must be considered a physiological law. We even speak of a "physiological clock."

But neither in space nor in the deep sea is there a sequence of day and night, to be used as a time indicator for man's physiological clock. In the deep sea, below 500 meters, there is eternal night. In space, beyond the atmosphere, there is, so to speak, day and night at the same time: a permanent bright sun--the symbol of day, shining from a permanent black sky--the symbol of night. Only when the astronaut moves through the shadow of Earth, is there a short exclusive night of about 30 minutes.

But the astronaut still needs rest and sleep after his exciting activities. It probably would be a "free running cycle," but still in the temporal frame of 24 hours with 7 hours of sleep, although not necessarily synchronized with the day-night cycle observed in any particular time zone on Earth. The same will be true on the Moon, where the day-night cycle lasts for about 27 days. Be that as it may, a space traveler is living beyond our geographical time zones, and this has activated an intensive study of the physiological nature of man's day-night cycle, or of his physiological clock.

The day-night cycle is even important in today's intercontinental travel by air. After a transoceanic flight; i.e., after crossing five or more time zones, a traveler experiences a phase shift between the geographic day-night cycle of the new location and his physiological cycle. He then is in a state of what can be called asynchronosis. It takes from 4 to 6 days to become completely adapted to the new time zone, or to become resynchronized. This is a new point in travel medicine and has some interesting consequences.

A diplomat or businessman should leave 2 or 3 days in advance of an important conference to be held on another continent, in order to become adapted to the local time there; or he should preadapt himself by retiring every evening, several days in advance of the trip, according to the time on the other continent, so that he will not be handicapped by a day-night cycle asynchronosis when he meets with his synchronized counterpart who has remained in his local time zone. If these measures cannot be taken, the traveler should keep in mind that for the first few days after eastbound flights, the afternoon hours, and after westbound flights, the morning hours, are the best times for scheduling important meetings. It has been reported that actors, athletes, and even race horses were not at their best when in the state of incomplete cycle adaptation. If a man ill with a fever arrives in the United States from Europe, by air, he will have in the first days after arrival, his maximum temperature not at 5 p.m. EST, but rather at 11 p.m. EST, which is 5 p.m. European time. This is important to know when taking the temperature of patient who has just arrived from a transoceanic trip by air.

All of these experiences and situations in space and atmospheric flight have led to intensive studies in laboratories and caves, in which man and animals have been exposed to different lengths of artificial day-night cycles and phase shifts, and the various body reactions (temperature, metabolic rate, circulation, etc.) have been observed.

Even isolated tissue cells show a day-night cycle, as manifested in a different multiplication rate, with one exception--cancer cells. They always multiply at a maximum level; they no longer obey geobiological laws. This gives the medical researcher a new angle--to look into the nature of cancer cells and perhaps to find new methods of treatment.

All in all, the sleep-rest and wakefulness cycle will attract greater interest in daily life and, particularly, in hospitals. Patients who have undergone a major operation notice that for at least a week their sleep and wakefulness cycle is more or less "out of order" due to pain-relieving drugs. They also notice that as soon as their sleep is again confined to night time, they have the feeling that they are on the road to recovery. The recognition that a certain amount (or we may say "dose") of sleep, timely placed in the day-night pattern, is essential to well being, has already led to the exploration of artificial methods to induce sleep; for instance, electronically, by new modern drugs having no side effects, and last but not least by hypnosis.

Of special interest to ophthalmology is the visual panorama in space, with its black sky despite a perpetually bright shining sun. The human eye, in the visible section of the solar electromagnetic-radiation spectrum, is an indispensable and unsurpassable sensor in the exploration of space. But there is also a hazard. Looking into the Sun can produce a retinal burn, the same as that observed after atomic flashes or when watching a solar eclipse with an insufficiently smoked glass. In milder cases this can cause a blinding effect which can last for minutes. The astronauts reported that they always avoided looking directly into the Sun for this reason. These potential hazards necessitate protective measures, preferably in the form of automatically functioning light-absorbing photoreactive glasses, which change their transparency quickly, according to the level of illumination. The development of such protective glasses will have some influence upon the manufacturing of sun glasses worn on sunny days on Earth. Studies of glare and blinding effects and developing means of protection will also be beneficial for safety in automobile traffic at night. It is known, from the ophthalmological literature, that after a solar eclipse, numerous people, especially children, must be treated because of retinal injuries. Space medicine will make parents, teachers, and the press more aware of the hazards involved in the observation of such astronomical phenomena, so that they are warned in advance of the danger.

As in so many cases, that which is hazardous to man can also be made beneficial for him. Simulated artificial solar rays concentrated into a minute intensive beam, are now used in ophthalmological clinics to fixate detached retinas, by heat coagulation of the surrounding retinal tissue, and to destroy small retinal tumors such as melanosarcomas. In this way surgery of the eye can be avoided. Very recently a new method to produce very powerful rays, LASER (Light Amplification by Stimulated Emission of Radiation) has been used for the same purpose.

The final goal of astronautics is, according to the meaning of the word, a flight to another celestial body. This has raised the problem of interplanetary contamination--contamination of Earth, via rockets, by microorganisms from other celestial bodies; and vice versa. Methods are being developed and employed for the sterilization of rockets. Such sterilization on a large scale, with new chemicals, may bring some new ideas into the medical sterilization techniques. This area is the link between space medicine and another important scientific field in the space age: astrobiology, or exobiology--the science that studies the question of indigenous life on other planets, or extraterrestrial life. Such studies must include the past--paleoastrobiology. In this respect Earth's atmosphere presents an interesting model for the conditions on a life-supporting planet, from its primeval hydrogen phase to the present oxygen phase, and it offers a stimulating platform for general medicobiological considerations.

I should like to mention only one example in this connection, which concerns bacteriology. In all probability there was a time during the Proterozoic era, some 2 billion years ago, in which the carbon dioxide content in the atmosphere was considerably higher than it is today. Recent bacterial studies have revealed that an increased concentration of carbon dioxide generally promotes the growth of bacteria. For many bacteria, the optimum lies between 5 and 10 volume percent of carbon dioxide. The pneumococcus belongs in this category. It is therefore not surprising that this coccus finds an ideal environment for a population explosion in the lungs, producing a severe pneumonia within a few days, since the alveolar air is much richer in carbon dioxide than the ambient air. The carbon dioxide optimum of bacillus tuberculosis lies between 2 and 3 volume percent. Carbon-dioxide-philic bacteria are perhaps very old, paleontologically.

If so, when inhaled, they return to their original medium, preserved in the inner atmosphere of our lungs or in certain tissues. Paleobiological and astrobiological studies no doubt will extend the spectrum of our knowledge in terrestrial bacteriology.

Finally, a few words concerning instrumentation. Aeromedical researchers, in the mid-fifties, constructed a portable respirator that provides adequate ventilation for acute and chronic apneic patients. This device was first used for transporting patients by air. It is now used in emergency cases and in treating paralytic polio.

In space medicine new methods are being developed and tested in spacecabin simulators and actual rocket flights for recording environmental factors such as oxygen and carbon dioxide pressures, humidity, and temperature; and new methods are being developed to keep them in physiologically acceptable ranges, as already mentioned. Oxygen sensors developed specifically for aerospace medical purposes, are now widely used to check the respiratory air of patients under anesthesia. Convenient and exact methods are required to record various physiological processes (body temperature, heart activity, brain activity, and others) by such means as electronic thermometers, electrocardiographs, electroencephalographs, etc., and the data are telemetered to Earth. Because of the tight economic logistics in space operations, all instrumentation must be based on the principle of minimization in weight and miniaturization in volume. From this astroinstrumentation and biotelemetry, hospitals will benefit by the development of medical electronics. All patients on the critical list may be electronically watched from a central recording room. These electronic devices may even sense critical conditions in advance. And it is not too far-fetched to expect that soon it will be possible for a physician to send the electrocardiogram, the electronic code of serological reactions in infectious diseases, etc., via communication satellites (such as the newly developed Telstar) to laboratories for diagnosis and consultation. Medical electronics is also influencing new concepts and theories concerning physiological functions themselves. This new field is called bionics: life functions interpreted from the standpoint of electronic theories. Finally, for reasons of economic logistics, multiple-purpose equipment is required in spaceflight. This might also find useful application in terrestrial survival equipment in cases of emergency. There is no doubt that certain definitions and terms of the medical astroglossary will enter the general medical vocabulary.

All in all, space medicine will not only make its contribution to the realization of manned spaceflight, which is its proper mission, but in addition, the aforementioned examples are sufficient to demonstrate that it will also be of benefit on Earth to medicine and biology in general. It will extend our geomedical and geobiological knowledge into a cosmic spectrum.

THE TWO-HUNDRED-YEAR JUBILEE OF THE DISCOVERY OF OXYGEN*

Hubertus Strughold, M.D., Ph.D.

Two centuries ago the chemical component of the air, oxygen, was discovered, an achievement that has led to a revolutionary era of progress in the history of mankind. Today everybody is familiar with oxygen and its significance for life, and yet this element has been known for only 200 years. There is a good reason for this: Despite the fact that oxygen is around us and in us, we cannot see it, cannot smell it, cannot taste it; in other words, we cannot perceive it with our senses. Furthermore, methods for chemical analysis were not available to explore it. It is therefore not surprising that this vital element remained hidden to our ancestors' knowledge for millenia.

But there was some philosophical anticipation about this mysterious substance in the air. Greek philosophers called it "pneuma" ("the breath of life"). In the Latin language "igneo-aerial spirit" ("fire air spirit") appeared. Leonardo de Vinci in the 15th century was the first to state that the air contains two gases.

In the 16th century the word "phlogiston" ("inflaming or burning principle") dominated the theories of the air's chemistry.

And then in the years 1772-1775 three scientists in three different countries discovered this unknown element and recognized its property as "fire substance" and "life substance": Wilhelm Scheele in Stralsund (1772), Joseph Priestly in London (1774), and Antoine-Laurent Lavoisier in Paris (1775) who named the gas "oxygen" in 1776. It is interesting to note that all three of these oxygen pioneers did not obtain this gas from the air. They collected it by heating the metal mercury oxide (HgO_2), kept in a vacuum glass container, by sunshine through a burning glass. Today, oxygen is obtained by liquefying air at low temperature, a process in which liquid oxygen is separated from the liquid nitrogen.

The discovery of oxygen has opened the gate to new research and development of tremendous dimensions in chemical, technological, biological, and medical sciences.

To mention only a few examples: Liquid oxygen has been used as one of the chemical components of rocket propellants and of the life support systems in aircraft, spaceships, and pressure suits which have made

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*Remarks following a lecture at USAF School of Aerospace Medicine, 1976.

possible man's advance on the vertical frontier with its highpoint of landing on the Moon. With oxygen in the background, terrestrial medicine has been expanded to aviation medicine, space medicine, and lunar medicine. In clinical medicine, oxygen treatment has saved yearly the lives of thousands of people, for example, artificial respiration and the successful treatment of gas gangrene by oxygenation in hyperbaric chambers such as the one here at the USAF School of Aerospace Medicine. This treatment was impossible 10 years ago.

All in all, the discovery of oxygen has been a turning point from the alchemy of the ancient and middle ages to the modern scientific chemistry. We are in a golden age of oxygen. This time period coincides with the Bicentennial of the United States, 1976.

It is certainly very appropriate to salute at the Bicentennial the 200-year jubilee of the discovery of oxygen, since during the present century in the United States many contributions for the benefit of mankind have been made as a result.

IMPACT OF THE CELESTIAL BODIES ON THE HUMAN MIND*
(Stars, Planets, the Moon, Comets, UFOs)

Hubertus Strughold, M.D., Ph.D.

From the time of the caveman to the modern era of the spaceman the star-covered sky has fascinated the human mind. This fascination is reflected not only in the terminology of the related exploratory sciences such as astronomy but also in numerous words of the common language. In some popular words the astronomical connection is obvious; however, we get a deeper insight into this question of terminology if we look into the past, into the origin of words. This is called "semantics." We might use "Astrosemantics of Related Scientific Terms and Popular Words" as the title for the main topic of our discussion. In addition to semantics, the devotion of the human mind is also reflected in pictures and activities.

Let us begin with the basic field of exploration of the sky--namely, the ancient astronomy now called "archaeo-astronomy" and the modern scientific astronomy which began with the invention of the telescope in the 16th century. The term "astronautics" that was coined in Paris in 1922 for "flight to the stars" became popular with the first satellite in 1957 and is now used for all activities in space.

The prefix "astro" is derived from the Greek "Astraea," the mythological goddess of justice, and the daughter of Jupiter or Zeus. After the fabled Golden Age, she left the Earth and became the constellation Virgo; thus, in astromythology a female was the first astronaut, or "astronautress."

The Russians use the terms "Cosmonautics" and "Cosmonauts." The word "cosmos" means jewel, and it was used by the early ancient Greeks for the stars, which they thought were jewels distributed over the ceiling of a velvet black dome. In the literature the word "cosmos" was used in the 16th century by Thomas Muentzer, in Stuttgart, Germany, in a book entitled Cosmography, in which he described the geography of Europe, North Africa, parts of Asia, and a few areas on this continent. At that time the designation "cosmos" included only the known countries on Earth; today we know more about the surface features on the Moon and Mars than was known in the 16th century about this new continent and the eastern part of Asia. Now the word "cosmos" is applied in the same sense as the term "universe."

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I should mention also that the word "cosmetics," an area of activities of all ladies, too, is derived from the word "cosmos"; its purpose is to make the face of a lady look like a jewel or like a glowing star.

If we like to emphasize the human life factors involved in space operations, "bioastronautics" and "biocosmonautics" are the logical terms. The medical aspects of flight along the vertical frontier have led to the terms "aviation medicine" or "aeromedicine," "space medicine," or both combined, "aerospace medicine." Lunar medicine, which deals with the medical evaluation of the environment on the Moon has played an important role in the Apollo missions and will do the same in a future Lunar International Laboratory called LIL; Mars medicine, too, has already appeared on the scientific horizon with regard to a Mars International Laboratory, MIL. All of these medical studies, together with terrestrial environmental medicine, are subdivisions of an all-embracing cosmic medicine.

Biology, the science of life as we know it on Earth, has been extended into astrobiology which looks for life on Mars.

In this connection I would like to mention also that the Russian Biologist, Professor Gabriel Tikhov, Director of the Institute for Astrobotany, Alma Ata, Siberia, has an astrobotanical garden with vegetation which, it was believed, could grow on Mars. In 1958, an American astronomer, Dr. Albert Wilson from Flagstaff, Arizona, visited this institute and gave Professor Tikhov my book, The Green and Red Planet - the Possibility of Life on Mars. Professor Tikhov gave him leaves from an ancient Chinese ginkgo tree to present to me and to someone in the United States who was very much for the support of the exploration of space. We decided that this was Senator Lyndon B. Johnson. When Dr. Wilson came back to San Antonio, we visited Senator Johnson in his office in Austin. He accepted with pleasure this astrobotanical gift from Professor Tikhov.

At this point it is very appropriate to include an impressive statement about space medicine in a letter written to me in 1958 by Lyndon B. Johnson, at that time Senator: "I must say that I have rarely encountered a field of scientific endeavor more interesting than this one. Nor is there any field of greater immediate concern to this country, and to the world, as we enter the Age of Space."

Now let us turn to the semantics of the heavenly bodies in the sky. The word "star" comes from the Anglo-Saxon "steorra"; other terms are "sterella" and the Latin "stella." These two words, "sterella" and "stella," now are frequently the first name for ladies.

The name of the dominant star, the Sun, is derived from the Nordic "Sunno," the god of the upper world. The ancient Roman Sun god was called "Sol." This is now found in all Latin languages. The Greek word for the Sun was "Helios" from "helio," which means bright, radiant. It is now used as a prefix of terms in astronomy and other scientific fields and even in medicine; for instance, heliotherapy.

The word "Moon" is of Gothic and Anglo-Saxon origin. These ancient people considered the Moon as their only time measure: from New Moon to Full Moon to New Moon. The Gothic word for measure was "mena"; the Anglo-Saxon "mona." They named that giant time clock in the sky, therefore, "mena," or "mona," which has been changed finally into "Moon." Mona is also the origin of "Monday" and of "month." The Greek name for the Moon goddess was "selena." The lady's name "Helena" is derived from "selena."

Concerning the planets, I would like to mention only Mars. The ancient Romans venerated that reddish, light spot in the sky as their god of war. When they had conquered some parts of Western Germany, they named the rebellious German tribes "Marsi." Interestingly, there are still cities in West Germany which have names related to Mars; such as Marsberg (Mars mountain) and Merseburg (Mars castle). My father's ancestors lived on a farm which was called "Mersenhof" (Mersen farm). When I was a young student I spent my vacation in that area; the farmers never called me Strughold Hubert; instead, Mersen Hubert.

Mars was also venerated by the Romans as god of agriculture. To honor Mars in both respects, as god of agriculture and god of war, some Roman coins have the picture of Mars on one side and, on the other side, the picture of an emperor. Mars, on these coins, carries on one side a spear as a symbol of war and, on the other side, a shovel as a symbol of agriculture.

The human respect for the celestial bodies in the sky is also expressed by their pictures on national flags. Of the 158 flags of various nations, 3 show a picture of the Sun, 6 have a picture of the New Moon with one or several stars, and 15 are decorated with one or a group of stars, such as in the United States flag. Texas, the second largest state in the United States, is honored by a big star in the blue part of its flag as a symbol of its name, the Lone Star State.

The highest ranks in the military service are symbolized on their insignia by the highest celestial bodies in the sky, the stars; namely, one-star general to a five-star general. Also stamps show pictures of the heavenly bodies, especially in South American countries. NASA has printed a money bill which shows the pictures of the first lunar astronauts.

The hairy stars called "comets" always attract the greatest interest everywhere. I was lucky to observe the Halley's Comet in 1910. This observation made me space-minded for my whole studies and profession.

All celestial bodies are in an orbit of some kind. The word "orbit" means the pathway of a natural or man-made satellite moving around a celestial body. Fifteen years ago one had to explain the meaning of an orbit; today, everybody knows what an orbit is. It even has become a slang expression. For instance, if somebody in a bar has had three highballs, he is said to be high in orbit. And, I remember a very amusing cartoon in which a secretary was sitting in a corner of an office taking dictation from her boss, who had the habit of walking around the table while dictating. At one point during the dictation the secretary interrupted him, asking, "Excuse me, what did you say during your last orbit?"

Unidentified flying objects, called "UFOs," always attract a great interest everywhere. The U.S. Air Force had a project to examine the stories about UFOs. Since they could not find any evidence for the existence of UFOs, they dropped their project called "Blue Book" 10 years ago.

The White House wants NASA to look into this mysterious matter again.* This was apparently triggered by the story that President Carter, when he was Governor of Georgia, sighted a UFO near Griffin, Georgia, one day in 1973. He described the object "bluish then reddish then luminous but not solid." The word "not solid" seems to be of particular interest to me because I saw a UFO twice. The first sighting was when I was on vacation in Port Aransas on the Gulf of Mexico. One evening in October around 7 o'clock (after sundown), I suddenly saw a flying object high in the sky coming from the direction of Galveston. It had the form of a saucer, was yellowish in color, and came closer and closer, then disappeared. Several minutes later an airplane flew over the area above me. It was my explanation that earlier this saucer phenomenon was caused by solar illumination of the exhaust gases. Several minutes later the solar rays were too high over the airplane's altitude. The exhaust of the plane was not visible and only the plane appeared in the sky. Several months later when I was at Randolph Field and walking in the evening to the Officers Club around 7 o'clock, I saw a flying saucer over Kelly Field. I waited again and the flying object flew lower and lower and suddenly it disappeared. This too was an airplane. Both of these UFOs appeared to be not solid. It was illuminated gaseous material which formed a trail behind the plane.

In two weeks the Christmas celebration starts. Several thousand years ago the Anglo-Saxons celebrated at the same time something which was related to the Sun. Namely, when, in the last part of December, the days became longer, the Germanic tribes celebrated this in honor of and gratitude to the Sun. In astronomy, the day when this starts is called "solstice." The Germanic tribes had festivals in the forests in honor of the Sun god and other Germanic gods like Thor, Odin, and Wodan. These celebrations took place during the nights for 14 days. They were called Wihennechten, which means devoted nights. This word, "wihennechten," is the origin of the present word "weihnachten." When Christianity entered the Germanic area, the word "Weihnachten" was kept. In Germany this word is still used for the Christmastime. It is also printed on the Christmas cards, named "Weihnachts carte."

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*Editor's Note: In January 1978 NASA rejected this request.

SOME THOUGHTS ABOUT THE STARS AT CHRISTMAS*

Hubertus Strughold, M.D., Ph.D.

Ever since the beginning of history, the star-studded sky has attracted the attention of man. Most especially have the planets and the comets captured their imagination. In adoration the ancient Greeks and Romans bestowed upon the planets the names of their highest deities, such as Mercury, Venus, Mars, Jupiter, and Saturn.

About 2,000 years ago the stars attained a special glory when a star guided the Three Wise Men from the Orient to the little town of Bethlehem. Ever since that time, the eyes of man are turned more often to the starry sky during Christmas season than at any other time of year. So the thought occurred to me that it would be quite fitting to choose as a theme, for this particular occasion, some remarks about the stars at Christmas.

It is a great honor and a pleasure for me to be here with all of you to talk about this subject, and I am especially grateful to your president, Mrs. Clements McMullen, and your Program Chairman, Mrs. Edward J. Kendricks, for this opportunity.

There are various thoughts concerning the stars that may come to mind during the Christmas season. For instance, one might ask:

How do you explain this "star of Bethlehem" from the astronomical point of view?

According to an earlier hypothesis, the star that guided the Three Wise Men to Bethlehem might have been a comet. Some have identified it with Halley's comet, which returns every 75 years and was last seen in May 1910. When I was a boy of 11, I used to follow this comet every evening, so long as it was visible, with my little telescope.

Since a comet moves so quickly across the sky, however, one could hardly have served as a guide. More recently, it has been suggested that the star of Bethlehem was, perhaps, a so-called supernova--a very brightly shining new star. Supernovae are stars that flare up with great brilliance--increasing from comparative obscurity until they attain

*Speech given at the Luncheon of the Military Civilian Club of San Antonio, San Antonio, Texas, 7 Dec 1953.

a brightness of 10 or even 100 million times that of the Sun. It takes about a year for this intense luminosity to wane to its original appearance.

Sometimes new stars are observed that are not quite as bright as supernovae; they are called novae. But the light emitted by a supernova is much brighter and can only be compared with the light emitted by the entire stellar system. The famous astronomer Tycho Brahe observed such a spectacular event in 1572. That star was visible even in broad daylight. The appearance of a similar superbright star in the year 1054 is recorded in Chinese and Japanese annals. The remnant of this supernova is probably the so-called Crab nebula.

All in all, over the past thousand years only three supernovae have been seen in our Milky Way. The last appearance of a supernova was in the Andromeda nebula, outside our Milky Way, in 1934.

It may very well be that the star of Bethlehem was a supernova. If this is true, the birth of Christ was heralded and accompanied by the arrival on Earth of the light from a new superstar with a brilliance never seen before or since.

The appearance of conspicuous stars and comets in the sky has always been regarded as the beginning of a new era. And with the appearance of the star of Bethlehem, the most important era in the history of mankind began--the Christian era.

The stars--their laws of motion and their physical nature--have been thoroughly studied during the past centuries with all the skill that scientists could develop. Today we know quite a bit about the physical and chemical processes within the stars that cause them to shine. We can even produce starlike matter artificially, to be used for the benefit or the destruction of mankind. It was truly thought appropriate to Christmas when, just a short time ago, the President of the United States proposed to the world that this originally heavenly matter be put to use only for peace.

We have a good many theories about the evolution of galaxies, extragalaxies, spiral nebulae, and clusters of stars. Today, indeed, we have very advanced knowledge of the expanse and distribution of the stars, and of the forces acting on them and within them. But the ultimate story behind the existence of the stars in the universe is, and always will be, a miracle to the human mind. And only such a miracle as that of a newborn star could properly herald the event which we celebrate at this joyous time of the year--Christmas.

An even greater miracle than a star, but not quite so spectacular, is a celestial body that bears life. We know with certainty only that one such body does exist. It is the planet on which we live--Earth.

The manifestation of life is a miracle in itself. And life in its millionfold varieties of appearance, is quite beyond our comprehension. After the telescope was invented, increasing the visual power of the human eye many thousand times, the planets appeared to be of a kind similar to our Earth. At once the question was posed: Are there other inhabited worlds or is the Earth a unique phenomenon? The very thought of a plurality of worlds soon captivated the imagination of astronomers, philosophers, theologians, and others. Are we alone as living beings in the planetary system of our Sun? Are we alone even in the whole universe? This too is a question which might engage our minds in days like those of Christmas.

In the search for an answer to these inviting questions, let us first consider our neighboring planets. The group of outer planets, such as Jupiter, Saturn, Neptune, Uranus, and Pluto, move in orbits in the chill, dark vastness of space, far distant from the life-supporting Sun. In such a deep-freeze environment, life is inconceivable. Mercury, the planet nearest to the Sun, has no atmosphere at all and is exposed to a mercilessly intense solar radiation. Venus, the second planet from the Sun, surrounds itself with an impenetrable veil of dense clouds and hides the secret of its surface features from the astronomer's eyes.

Last but not least is the planet Mars. The atmosphere and surface of this planet can be studied carefully and in great detail. Environmental conditions on Mars suggest the possibility of life--the kind of life we know here on Earth. Dark areas show seasonal color changes from green to yellow in the spring, from yellow to brown in the fall, and then to grey in the winter; these changes make the presence of an Earthlike vegetation seem a probability. But the low mean temperature and the lack of oxygen on Mars may permit only the lower forms of life, such as we see in lichens and mosses on Earth. And since the nights are extremely cold, even colder than those in Alaska, active life may be possible only during the day, in the warmth and light of the Sun. During the night they may fall into a dormant state, comparable to hibernation. If this is so, on Mars every morning would be spring; every noon, summer; every evening, fall; and every night, an arctic winter; and the next morning, springtime again.

Such is the picture of life on Mars, drawn from a strictly scientific point of view but shaded with a few strokes of imagination.

If Mars can indeed be considered as an abode of life, it is only a poor relative of Earth. For truly, Earth alone is blessed with all the necessities that make life on the highest level possible. It is indeed the center of life in our solar system.

But what about the planets belonging to other stars, those similar to the Sun? There are countless stars in the universe similar to our Sun. Astronomers have calculated from the way that some of the nearer

Sunlike stars behave that they must have planets. Moreover, they estimate that about 100 million out of the 100 quadrillion stars in the universe might have developed families of planets.

Someday, with the help of new types of astronomical tools, it may be possible to determine definitely whether or not they are surrounded by planets like our Sun. But because of their great distance, which can be expressed only in light years, we will probably never be able to learn whether or not those other planets beyond our solar system harbor life as we know it, or life of any different kind. This is a subject which surely will remain a matter of delightful speculation and imagination for the rest of time.

In conclusion, I believe you will agree that nothing else could give us a better inspiration for the Christmas season than to gaze into the starry sky, with all the beauty and the miracles it has to offer. But let us again turn our thoughts for a moment to our home Sun and to our home planet. After returning from a long trip we often say "there is no place like home." Indeed, there is no better planet than our home planet--this celestial body, blessed with oceans, with a salubrious atmosphere, a variety of landscape in the form of wide-open plains such as those we find here in the great Lone Star State, blessed with beautiful valleys and snow-covered mountains, gifted with a luxuriance of colorful plants and legions of species of animals. It is a planet destined as the home of mankind.

MARS--THE ROMAN GOD OF WAR AND OF AGRICULTURE

Hubertus Strughold, M.D., Ph.D.

In ancient times the Romans venerated the reddish looking planet Mars essentially as the god of war and worshipped him in many festivals. But Mars seems also to have been an agricultural god, the protector of the fields against disease and unfavorable weather. Several plants such as the fig tree and the laurel were associated with him, according to the book Larousse World Mythology.

This second deity role is not so well known as the first one. Fortunately, ancient Roman coins with Mars' picture are still available and illustrate the two Roman aspects of Mars as deities. For many years I have collected Roman coins with one side of the coin showing an emperor and the other side, the god Mars. The Roman coin called "denarius" has on one side the god Mars with a spear as a symbol of war in his right hand and a shovel as a symbol of agriculture in his left hand (Fig. 1). This Mars picture, which is found on many other Roman coins, can be considered as proof of the mythological story that Mars was also celebrated as god of agriculture.

Figure 1. Roman coin showing the god Mars.

SOLAR ENERGY DICTIONARY

Hubertus Strughold, M.D., Ph.D.

INTRODUCTION

Solar energy, which has been for several billions of years the natural energy for the Earth's biosphere (plants, animal kingdom, and *Homo sapiens*), is *on the way in* to be used artificially, indirectly and directly, and to substitute other sources of energy, which are *on the way out*.

The technologic and biologic words or terms connected with this modern development will enter the common language; therefore, it is very appropriate to collect them in a *solar energy dictionary* or *minidictionary*. In several years the terminology of solar energy which has been exclusively the language of astronomers, environmentalists, and engineers will enter the public language, just the same as that of electricity, air conditioning, etc. Some solar terms are, of course, already found in the large dictionaries, but here they are put together and extended to a greater number in the form of a special minidictionary. And finally, *terminology* explains the meaning of words in their present sense. In addition to this, the words are traced back to the original in ancient Greek, Latin, and Anglo-Saxon. This is *semantics*, which makes the terms better understandable and more attractive.

A

angstrom	Unit used in measuring the wavelengths of light and other rays; one ten-billionth of a meter. Named after a 19th century Swedish physicist, Anders J. Ångström.
aphelion (aphel)	Point in the orbit where a planet or comet is at its greatest distance from the Sun. The Earth is at aphelion on about July 1. The opposite point, closest to the Sun, is called Perihelion.
array	From Latin *arredare*: to put in order. Regular arrangement, an orderly display (for instance, of solar cells).
aurora	In Latin mythology - the Goddess of Dawn. Streams of sunlight appearing sometimes during the night in the northern hemisphere: aurora borealis; in the southern hemisphere: aurora australis.

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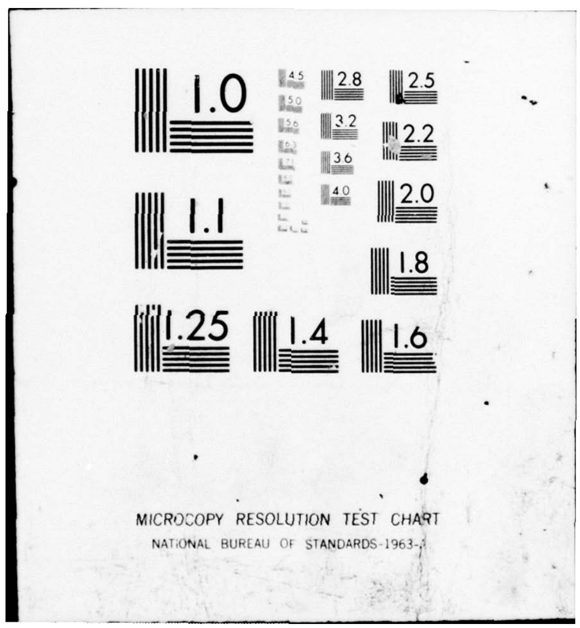
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B

BTU	British Thermal Unit: amount of heat needed to increase the temperature of one pound of water by 1°F = about 252 gram calories.

C

caloric	Pertaining to heat.
calorie or calory	From Latin calor: heat. The amount of heat needed to raise the temperature of 1 cm^3 or 1 gram of water by 1°C = 1 cal or gram cal. 1 kilocalory or Cal = 1000 cal. The human body produces about 2400 Cal per day.
celsius scale	Centigrade temperature scale, named after its inventor, the Swedish astronomer Anders Celsius (1701-1744).
chromosphere	A thin surface layer of relative transparent gases above the photosphere of the Sun.
circadian cycle	From Latin circa and dies = around one day. Introduced by Prof. Franz Halberg, Minneapolis; the day-night cycle of sleep and wakefulness with sunset and sunrise as the time indicators.

E

earthlight	Reflected sunlight, as seen from space and the Moon.
ecology	From Greek oikos = Haus or Habitat. Ecology is the science about the habitat (introduced by Prof. Hecker, Germany, 1870).
energy	From Greek Energeia: in work; in power, to do work.
environment	From environ + ment = surroundings.
ERDA	(Federal) Energy Research and Development Administration (Location: Washington, D.C.).
erg	Work unit; an absolute cgs unit of work representing the work done by a force of one dyne acting through a displacement of one centimeter in the direction of the force.

F

furnace	From Latin fornace related to fornus oven; to heat like a fornace, solar furnace.

G

geothermal or geothermic	From Greek gaia - Earth heat. Refers to the heat from the Earth inside.
greenhouse	Glass-covered structure of various sizes placed in proper location to sunlight for growing green plants.

H

helio-	Referring to the Sun.
heliocentric theory	Theory of Copernicus, 16th century, according to which the Sun is the center of the planetary system. It replaced the geocentric theory of Ptolemy which considered the Earth as the center.
heliolatry	Sun worship.
heliologist	Person skilled in heliology.
heliology	The science of the Sun.
heliophile	Loving sunlight.
heliophobe	Fearing sunlight.
heliopolar	Of or having to do with the pole of the Sun.
Helios	In Greek mythology, the name for the Sungod, son of Hyperion. Helios is pictured driving a chariot drawn by four horses through the heavens, later identified with Apollo.
helios satellite	Sun-orbiting satellite, a combined project of NASA and Germany of a solar probe revolving around and close to the Sun, to record the Sun's activity. So far, helios A and B are in orbit. Helios A was launched in 1975 and helios B in 1976.
heliostat	From Greek helio and Latin status. Equipment which always faces toward the Sun.

heliotherapy	Treatment of skin disease (for instance, psoriasis) by means of carefully controlled exposure to sunlight.
heliotrope	From Greek trepein, to turn in the direction of the Sun, used for plants.
hertz	Unit of frequency = 1 cycle/sec. Named after a 19th century German physicist, Heinrich R. Hertz.

I

illuminance	The intensity of light coming from a light source measured in meter-candle, called lux (see lux).
illuminate	Make bright with light.
illumination	The action of illuminating.
irradiance	The intensity of radiation.
irradiation	Emission of radiant energy.

J

joule	The absolute mks unit of energy or work = 10^7 ergs or approximately 0.7375 foot-pounds. Named after the 19th century English physicist, James P. Joule.

L

laser	Light amplification by stimulated emission of radiation.
light	Section of the electromagnetic spectrum that is visually perceptible by the eye.
luminous	Light emitting, shining.
lux	Unit of measuring the intensity of illumination: 1 lux = 1 meter-candle.

M

maser	Microwave amplification by stimulated emission of radiation.

microwaves	Electromagnetic waves between 300,000 and 300 megahertz in frequency (between 100 centimeters and 1 centimeter in wavelength).
moonlight	Reflected sunlight.

<u>O</u>

OSO	Orbiting Solar Observatory. Earth-orbiting satellite with solar recording equipment. Eight of these satellites have been launched since 1962 in the United States.
oxygen O	Element 8 in the periodic system.
oxygen O_2	The two-atomic oxygen molecule.
ozone	Three-atomic oxygen molecule.
ozonosphere	Ozone layer within the Earth's atmosphere between 15 and 25 km altitude. It is produced by solar ultraviolet rays; protects life on Earth from solar-ultraviolet rays.

<u>P</u>

panel (solar)	From Latin <u>pannus</u> = piece; section of a wall forming a board for instruments, such as solar cells.
perihelion	Point in orbit where a planet or comet is closest to the Sun. The opposite point, farthest from the Sun, is called <u>aphelion</u>.
petroleum	A fossil fuel; an oily flammable bituminous liquid that may vary from almost colorless to black.
photo	Regular appearance of light.
photon	Particle of light.
photophobic	From the Greek <u>phos</u> - photos = light. Tendency of plants to turn away from light.
photosphere	The light-emitting outer layer of the Sun.
photosynthesis	Production of organic material from carbon dioxide and water by the action of light on the chlorophyll in green plant cells.

phototrope	Tendency (of plants) to turn to light.
photovoltaic cell	Device that converts solar radiation into electricity; also called solar cell.

<u>R</u>

radiation	From Latin <u>radiate</u>. Process of emitting radiant energy in the form of waves or particles.
ray	From Latin <u>radius</u> - fine line of light.
retinal burn	See "solar eclipse blindness."

<u>S</u>

SERI	Solar Energy Research Institute - located near Golden, Colorado, and operated by the Midwest Research Institute (MRI), Kansas City, Missouri.
sol, solis	Latin words for the Sun.
solar	Of, to do with, produced by the Sun; referring to the Sun.
solar activity cycle	11-year-long cycle.
solar animal	Animals that have developed organs for absorbing solar heat; such as the dinosaur dimetrodon grandis.
solar architecture or solararchitecture	Design of buildings to make use of solar heat for air conditioning.
solar battery	A device that uses silicon cells to convert solar light into electricity.
solar cell	A photovoltaic cell that converts sunlight into electrical energy.
solar constant	The amount of heat from the Sun, that reaches 1 square centimeter (cm^2) of the Earth's surface in 1 minute if no heat were lost in the atmosphere and the Earth's surface were perpendicular to the Sun's rays.
solar corpuscular rays	Cosmic radiation originating from the Sun.

solar cycle	Periodic increase and decrease in the number of sunspots (11 years).
solar eclipse	The obscuration of the light of the Sun by the Moon.
solar eclipse blindness	Blindness (retinal burn) caused from looking directly at the Sun without proper eye protection during a solar eclipse.
solar facula	Bright patches in sunspots.
solar flare	A sudden and temporary outburst of energy from the Sun's surface.
solar home	Building with equipment for solar heating and cooling.
solarium	A room in a hospital exposed to the Sun for heliotherapeutic treatment of illness by application of sunbaths.
solarization	The process or effect of solarizing.
solar physics	Astronomical study of the Sun.
solar prominences	A filamentlike protuberance from the chromosphere of the Sun.
solar radiation	The total electromagnetic radiation emitted by the Sun.
solar satellite power station in space	Synchronous satellite 35,000 km above the Earth, 15 km^2 large, covered with solar cells, which convert solar light into electricity, which is transmitted to antennas on Earth by a beam of microwaves and reconverted to electricity (a project suggested by Dr. Peter Glaser).
solar wind	A continuous stream of charged particles ejected by the Sun and extending to and beyond the distance of the Earth.
solstice	Summer - about June 22, and winter - about December 22, at which time the Sun is farthest from the Earth's equator.

Sun — Derived from the name of the ancient gothic Sungod Sunno

Symbol: ⊙

Astronomical basic data:

Mean distance from the Earth: 93,000,000 miles

Diameter: 864,000 miles (109 times that of the Earth)

Mass: 22×10^{27} tons (332,000 times that of the Earth)

Chemical process: Fusion of hydrogen into helium

Layers of the Sun: Photosphere and chromosphere

Temperature at the center of Sun: 4×10^{60} Kelvin

Photosphere: 5750° Kelvin

Sunspots: Areas on the Sun's surface, less bright than the surrounding areas.

Sundance — A religious dance in worship of the Sun performed by certain American Indian tribes at solstice.

Sunno — The ancient gothic Sungod.

sunshine — Solar light strong enough to produce shadow.

sunshine vitamin — Vitamin D, which is produced in the skin, and helps to strengthen the bones.

sunstroke — A condition in which the human body is overcome by excessive solar heat and not able to get rid of it. Body temperature up to 105°F or 40°C.

suntan — Yellowish-brown color given to the skin by exposure to the Sun.